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PROGRESS REPORT

METAL CONCENTRATIONS IN MARINE FISH AND SHELLFISH FROM BOSTON AND SALEM HARBORS, AND COASTAL MASSACHUSETTS

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ABSTRACT

Trace element levels were measured in the softshell clam *Mya arenaria*, blue mussel, *Mytilis edulis*, surf clam, *Spisula solidissima*, ocean quahog, *Arctica islandica*, American lobster, *Homarus americanus*, and winter flounder, *Pseudopleuronectes americanus*. Softshell clams were collected in Boston and Salem Harbor. Surf clams, blue mussels, and ocean quahogs were collected in randomly selected areas of Coastal Massachusetts. Lobster and flounder were also collected in the two harbors and random coastal areas. The survey was undertaken as part of the Division of Marine Fisheries Contaminant Monitoring Program and consisted of tests for six metals: cadmium, chromium, copper, mercury, lead, and zinc. Edible tissue was prepared from each species. Metals, exclusive of mercury, were extracted with hot concentrated nitric acid/30% hydrogen peroxide. Mercury was extracted from a separate subsample with warm nitric/sulfuric acid and potassium permanganate/potassium persulfate solutions. Mercury concentrations were determined by cold vapor atomic absorption spectrophotometry (AAS). The other five metals were analyzed using flame AAS. Metal levels for each species were compared with results from other surveys conducted in the New England coastal areas and Boston and Salem Harbors. Metal concentrations of all species were similar to results reported elsewhere.

Significant intraspecies and interspecies variations in metal concentrations appear in samples collected over a period of three years (1984 - 1986). Intraspecies differences detected in lobster and winter flounder from coastal and harbor areas were similar to differences found in other studies, even though our coastal samples were closer to shore. Depending upon the particular metal, interspecies differences among the four bivalve molluscs encompassed several orders of magnitude. Possible anthropogenic additions of copper and zinc to harbor lobster could not be determined because the natural biological variations in copper and zinc could not be ascertained. Cadmium levels in the bivalves and lobster may have been affected by natural variations in the production of cadmium-binding proteins within these species. High chromium levels in Salem Harbor softshell clams and lobster suggest environmental contamination due to high chromium levels in Salem Harbor sediments.

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INTRODUCTION

Contaminants entering the marine environment have the potential for reducing the survival of marine organisms. When present in sufficient concentrations organic and inorganic compounds can have chronic or acutely toxic affects upon marine species. At sublethal concentrations chronic affects can cause decreased survival by reducing fecundity, impairing feeding, increasing metabolism, causing formation of cancerous tumors and reducing successful larval development (Weis and Weis, 1989). It is necessary that Massachusetts monitor the extent of environmental contamination in order to help manage and protect the Commonwealth's marine resources. These resources contribute approximately one billion dollars annually to the Commonwealth's economy by way of the commercial fishing industry (Massachusetts Division of Marine Fisheries, 1985).

In response to growing concerns over the impact of contaminants on marine resources, the Division of Marine Fisheries initiated a small-scale contaminant monitoring program designed to measure tissue concentrations of organic and inorganic contaminants in marine species of commercial and recreational importance. The spatial scope of the program encompasses all territorial waters of the Commonwealth with additional focus on Boston and Salem Harbors. The goal of the program is twofold:

1. Obtain baseline contaminant information for marine species in certain polluted harbors and assumed relatively unpolluted coastal areas.

2. Create time series information to monitor changes in contaminant levels within and among habitats and species.

Depending on the particular element or combination of elements and their concentration(s), trace metals can be harmful not only to marine organisms but to humans as well. Elevated metal concentrations have been reported in marine species and sediments from other urban and coastal areas throughout the United States (Reid et al., 1982; Breteler, 1984; NOAA, 1984, 1987, 1988, & 1989). This report provides information on the edible tissue concentrations of trace elements (heavy metals) in softshell clam, *Mya arenaria*, blue mussel, *Mytilus edulis*, surf clam, *Spisula solidissima*, ocean quahog, *Arctica islandica*, American lobster, *Homarus americanus*, and winter flounder, *Pseudopleuronectes americanus*. Where possible, metals concentrations were tested for spatial, seasonal, and annual variations, and compared with existing trace metal

information for these species for coastal Massachusetts and offshore areas of New England. The initial presentation of these results provides needed baseline information for a survey of several elements over a wide geographic area of coastal Massachusetts. This information will help assess the extent of trace metal contamination for important marine species both in the harbors and open territorial waters of the Commonwealth.

MATERIALS AND METHODS

Field Sampling

Winter flounder, *Pseudopleuronectes americanus*, and American lobster, *Homarus americanus*, were chosen as the representative fish and crustacean for harbor and coastal samples. In Boston and Salem Harbors the softshell clam, *Mya arenaria*, was sampled as the representative bivalve mollusc. Three stations for lobster and flounder, and three stations for softshell clams were located in each harbor (Figures 1 & 2). Lobster samples collected in 1984 near the outfall pipe of the South Essex Sewerage District (SESD) were included with Salem Harbor stations. Harbor flounder and lobster samples were collected with an otter trawl from the Division of Marine Fisheries (DMF) R/V FC Wilbour. Softshell clams were gathered from the intertidal zone using a standard clam fork.

Coastal bivalve molluscs included the surf clam, *Spisula solidissima*, ocean quahog, *Arctica islandica*, and blue mussel, *Mytilis edulis*. These bivalves, as well as, coastal flounder, and lobster samples were collected using a random sampling regime during the DMF Resource Assessment Survey cruises (Figures 3-5). Survey cruise numbers 8491, 8492, 8591, and 8592 correspond to samples obtained in Spring, 1984, Fall, 1984, Spring, 1985, and Fall, 1985, respectively. Spring cruises occurred in May, Fall cruises occurred in September of each year. Samples were taken by otter trawl from the chartered National Oceanic and Atmospheric Administration (NOAA) R/V Gloria Michelle. All lobster samples were legal size. Flounder and lobster samples were individually analyzed, bivalve samples were generally composited in order to provide sufficient tissue for analysis. The locations of the various sample sites are shown on the maps in Appendix B.

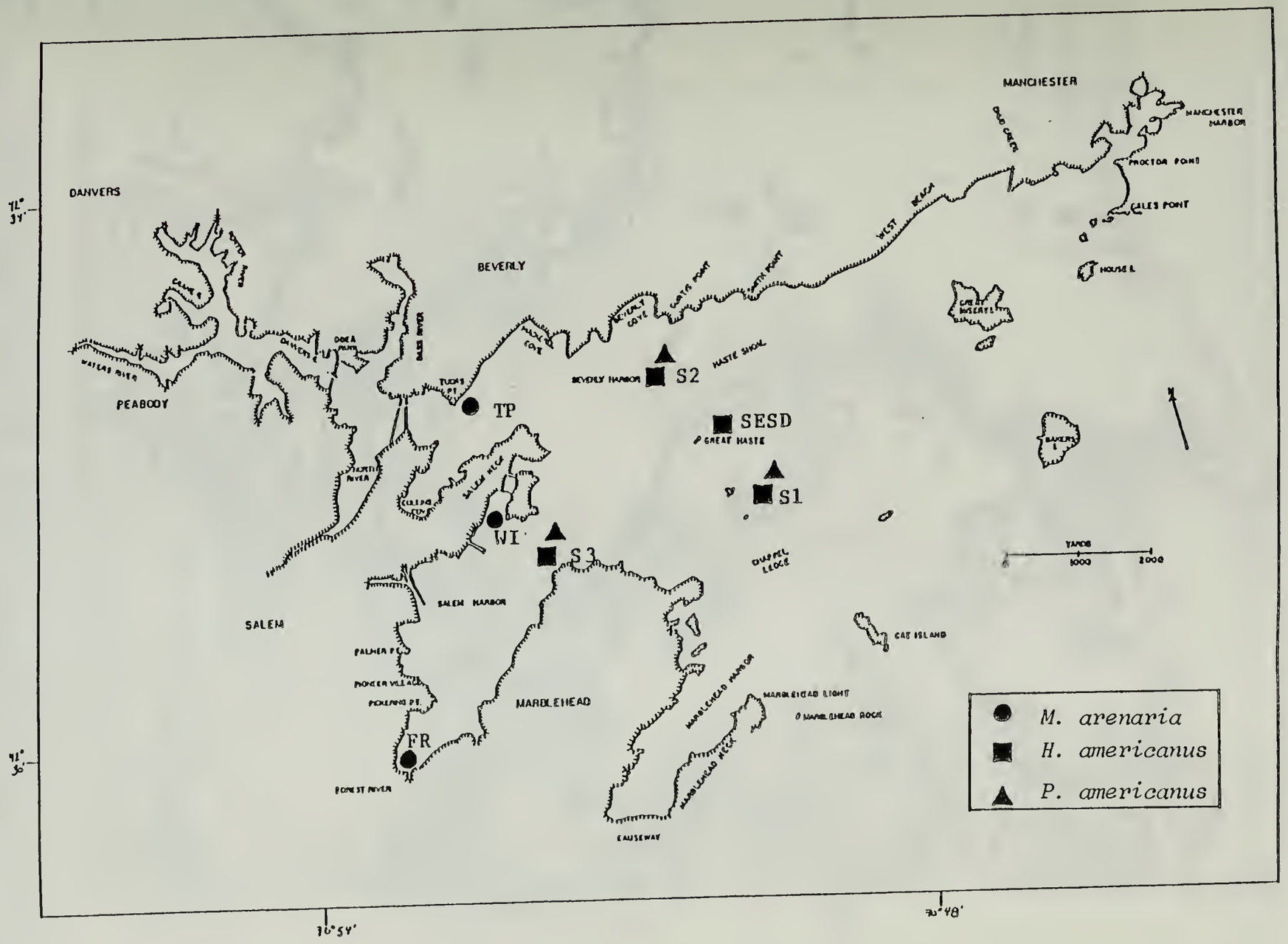


Figure 1. Station locations for the collection of softshell clam, American lobster, and winter flounder.

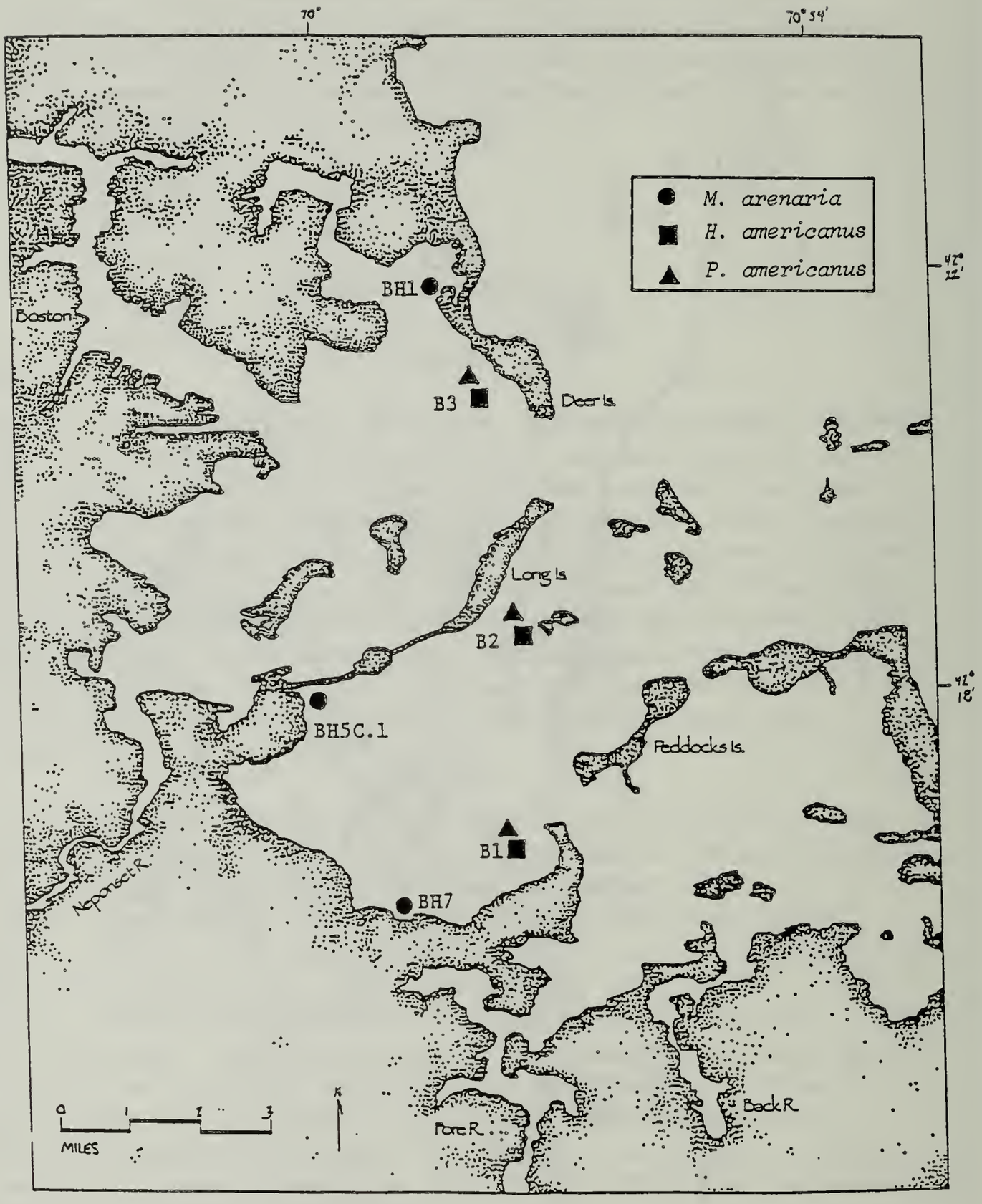


Figure 2. Station locations for the collection of softshell clam, American lobster, and winter flounder in Boston Harbor.

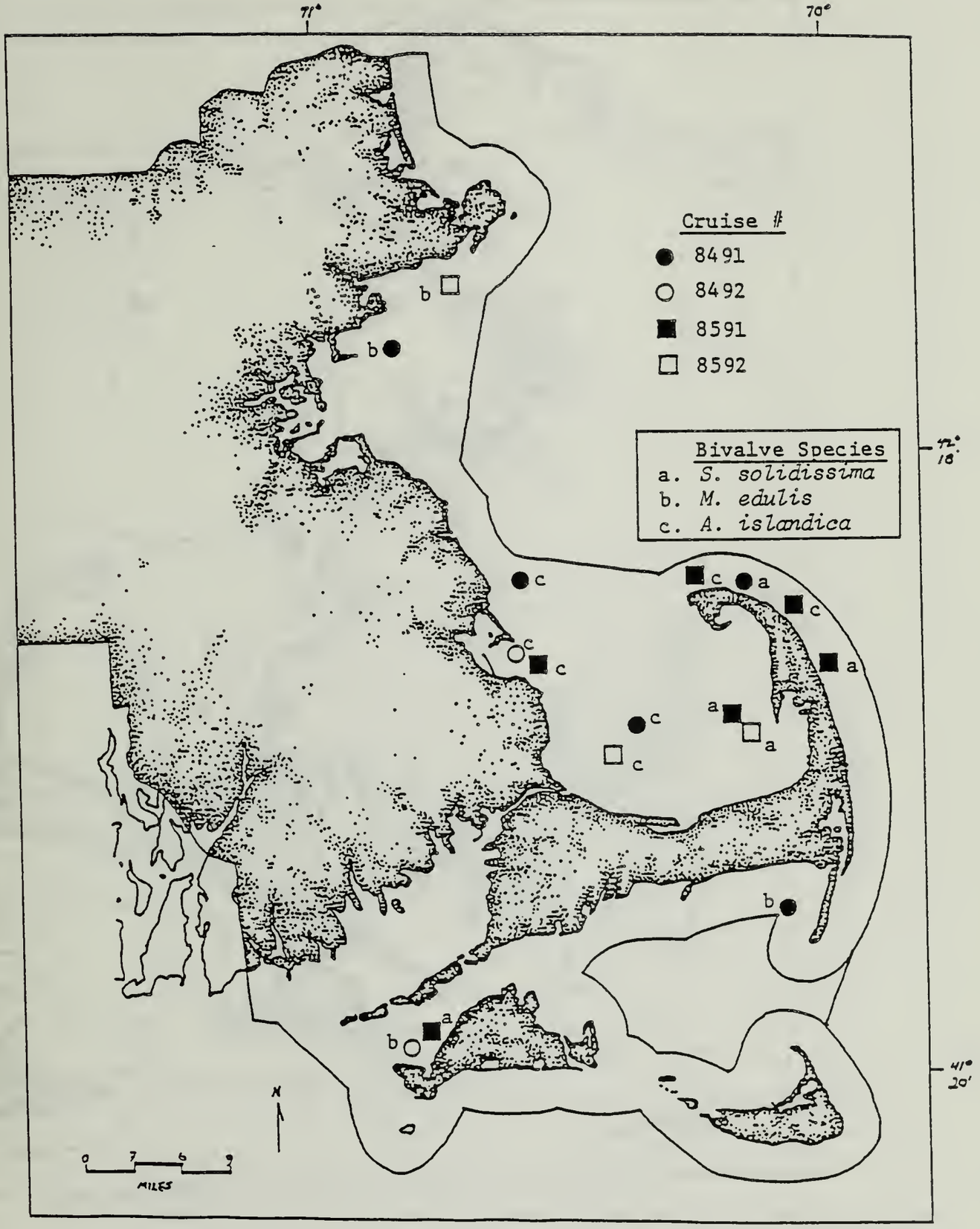


Figure 3. Station locations for the collection of surf clam, blue mussel, and ocean quahog during cruise 8491 (Spring 1984), 8492 (Fall 1984), 8591 (Spring 1985), and 8592 (Fall 1985).

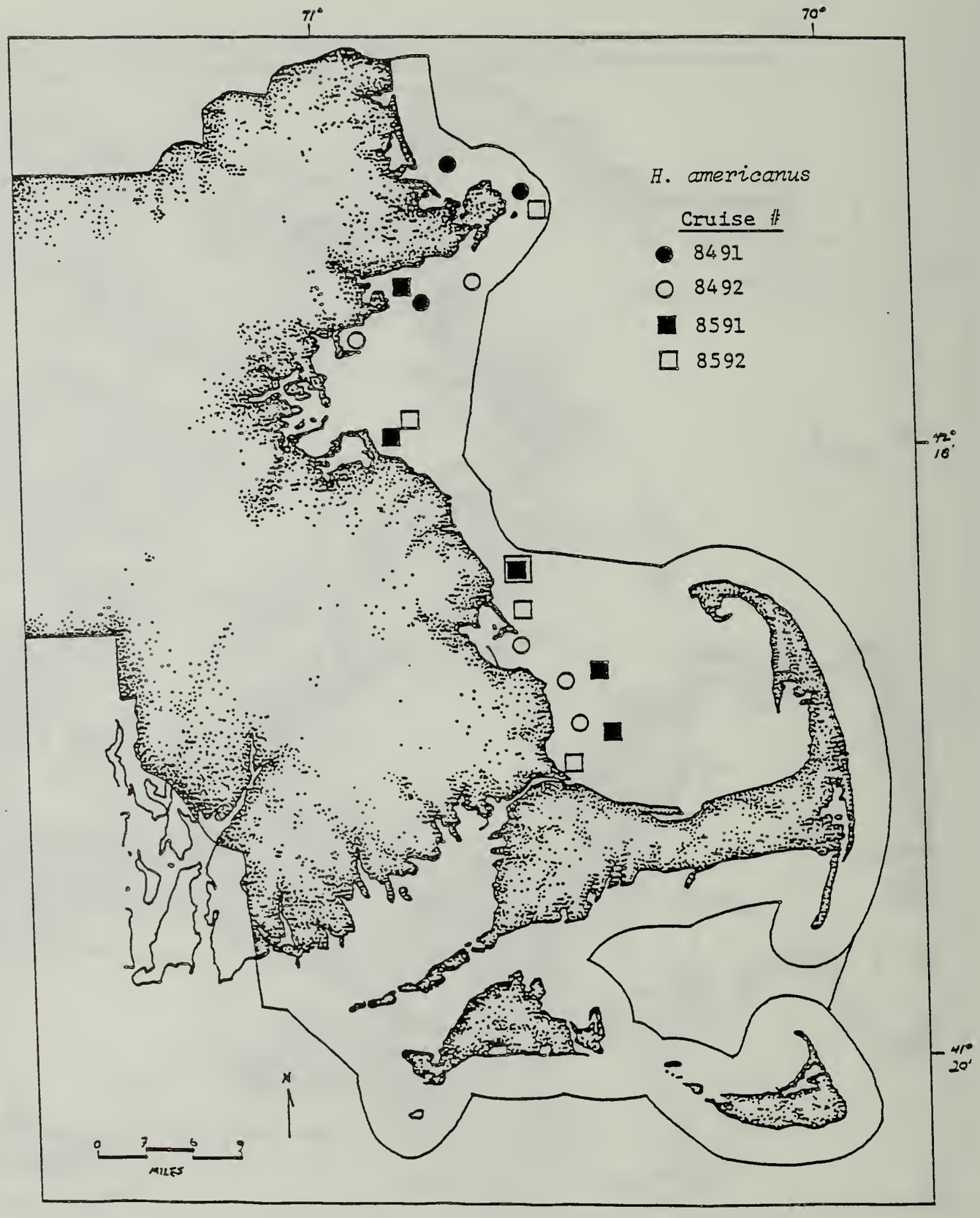


Figure 4. Station locations for the collection of American lobster during cruise 8491 (Spring 1984), 8492 (Fall 1984), 8591 (Spring 1985), and 8592 (Fall 1985).

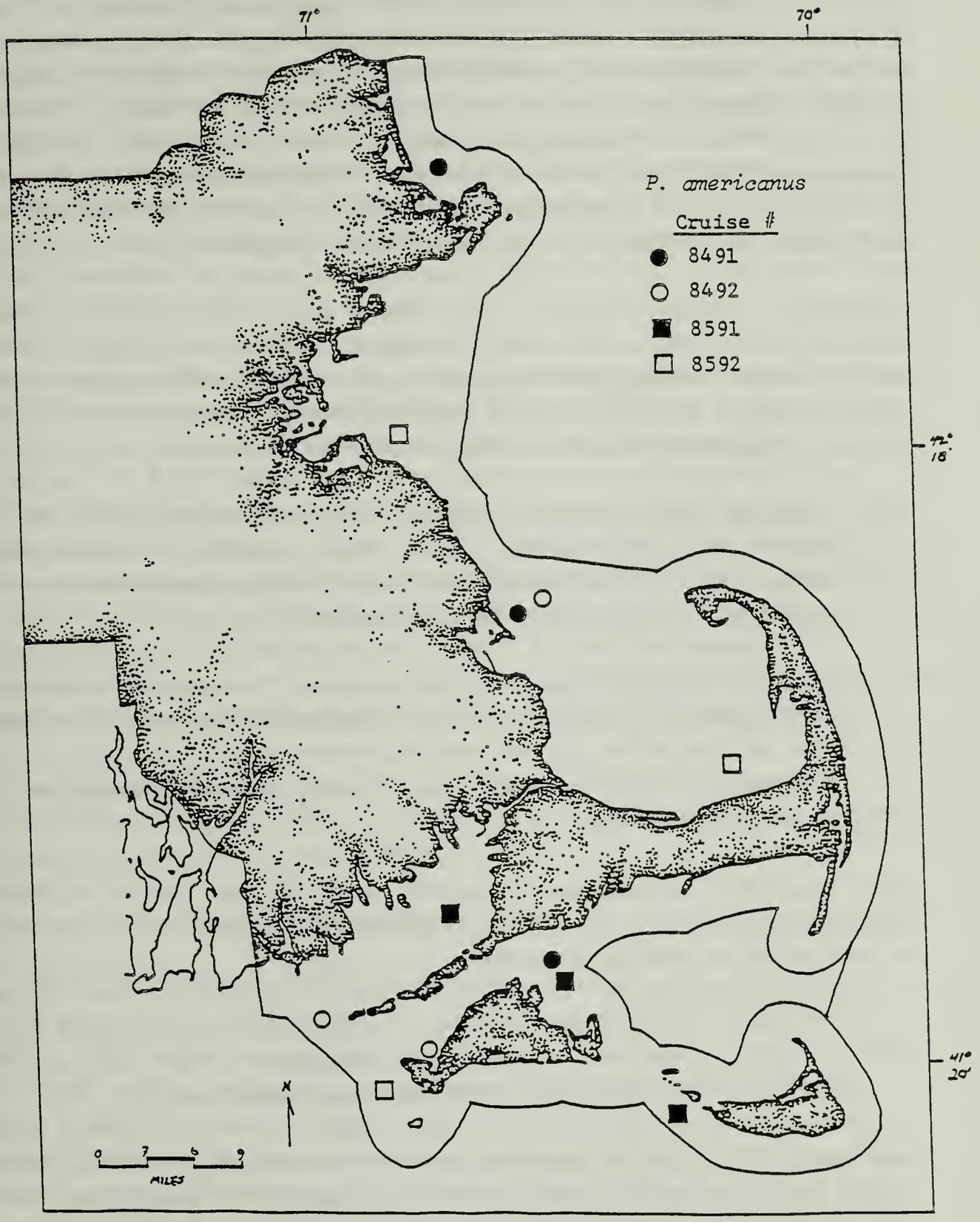


Figure 5. Station locations for the collection of winter flounder during cruise 8491 (Spring 1984), 8492 (Fall 1984), 8591 (Spring 1985), and 8592 (Fall 1985).

Sample Preparation and Analysis

Tissues for analyses were prepared in the laboratory from the edible portions of frozen specimens. Samples were thawed to the point where they could be handled but remained sufficiently frozen that body fluids were retained. Flounder samples consisted of the combined dorsal and ventral fillets from one individual. Lobster samples included tail meat, claw meat, tomalley (hepatopancreas), and gonad or ovaries. Bivalve samples included all soft body parts normally considered edible and were generally composites of several individuals as indicated in the data tables (Appendix C).

All knives, forceps, scissors, and blender cups used to prepare samples were composed of stainless steel and thoroughly cleaned and acetone rinsed before use. A wooden working platform was covered with acetone rinsed aluminum foil and placed in a stainless steel drainage trough. Samples were cleaned of surface contaminants before being prepared as follows:

Flounder: filleted and skinned using a filleting knife and spatula. Both (dorsal and ventral) fillets were transferred to one blender cup using a spatula and homogenized using a high speed blender, except as indicated in the data tables (Appendix C).

Lobster: picked using surgical scissors, forceps, and spatula. Tissues were placed in a blender cup and homogenized using a high speed blender.

Bivalve mollusks: shucked into a blender cup and homogenized using a high speed blender.

After blending, all samples for metals analysis were stored in plastic sample bags and kept frozen. As needed, samples were thawed and extracted according to methods described in Appendix A.

Analytical Methods
Procedure for Metals excluding Mercury

Most metals (Cd, Cr, Cu, Pb, and Zn) were extracted from homogenized edible tissue using hot concentrated nitric acid and 30% hydrogen peroxide. Extracts were analyzed by flame atomic absorption spectrophotometry using a Perkin-Elmer Model 3030B Atomic Absorption Spectrophotometer (AAS). Elements detected by flame AAS were cadmium, chromium, copper, lead, mercury, and zinc.

Mercury was analyzed by a separate procedure. The AAS was optimized according to manufacturer's specifications to the primary (most sensitive) absorption wavelength. Calibration standards (Fisher Certified Atomic Absorption Reference Solutions) were prepared in 2% v/v HNO_3 (70.0 - 71.0% 'Baker Instra - Analyzed' Reagent for Trace Metal Analysis, deionized H_2O of 2 megaohm purity). Calibration standards encompassing the expected range of sample values were used to define an analysis curve for each element. Accuracy of each curve was verified by comparison with at least two appropriate US EPA Water Pollution Laboratory Performance Evaluation Trace Metal (WP series) samples. Sample absorbance was read three times and the mean value was recorded and used in subsequent calculations. This constituted one analysis.

Quality control extraction blanks were analyzed at least three times during analysis of their corresponding sample group; before the first sample, after the last sample, and after every 10% of samples in the corresponding extraction group. U.S.EPA Water Pollution Quality Control Samples, Trace Metals in Fish, were used as standard reference material (SRM) for this study. Spiked blanks were also analyzed (Table 1a). Sample triplicates and spiked samples were extracted and analyzed as 10% or more of sample load. Recoveries of 80% to 120% of expected value were deemed acceptable with most values falling between 90% and 110% of expected value. Extraction groups with recoveries outside these values were re-extracted. Samples which could not be re-extracted due to lack of tissue were noted with their recovery amounts (Appendix C). Reported tissue concentrations are not corrected for spike recovery. Log books were maintained for all samples received, prepared, digested, and analyzed on the AAS. Raw data and calculations for all elements (including mercury) were stored on hardcopy.

Procedure for Mercury

Mercury was extracted from the homogenized edible tissue with warm nitric / sulfuric acid solution and permanganate / persulfate solution. This extract was analyzed by cold vapor atomic absorption spectrophotometry using a Perkin-Elmer Model 3030B Atomic Absorption Spectrophotometer with a Perkin-Elmer MHS10 mercury hydride generator. The system was optimized to the absorption wavelength for mercury (253.7 nm) according to manufacturer's specifications. Calibration standards encompassing the expected range of sample values were used to define an analysis curve. Accuracy of the curve was verified by comparison of standards' absorption values with at least two appropriate US EPA Water Pollution Laboratory Performance Evaluation Trace Metal (WP series)

Table 1a: Analyses of EPA Standard Reference Material

Water Pollution Quality Control Samples
Trace Metals in Fish
(μg/g dry wt.)

Analysis Number	Cd	Cr	Cu	Pb	Zn
1	2.5	0.25	2.5	0.83	43.75
2	0.000	0.23	1.36	0.00	40.5
3	0.14	0.26	2.14	0.29	41.6
4	0.200	1.55	2.25	1.50	47.50
5	0.154	0.31	1.89	2.31	28.85
Reference Values					
Mean	0.16	0.58	2.21	0.26	43.75
Range	MDL- 0.32	MDL-1.34	0.93-3.49	MDL-0.62	35.5-51.7

Note: MDL = method detection limit

samples. Calibration curves which did not produce values within 5% of expected values were recalibrated. Samples were analyzed using a modified Hatch and Ott (1968) procedure. The prereductant solution was 24% w/v $(NH_2OH)_2 \cdot H_2SO_4$ ('Baker') in 12% NaCl ('Baker Analyzed' Reagent), prepared in deionized water of 2 megaohm purity. The stannous chloride solution was 10% w/v $SnCl_2 \cdot 2\ H_2O$ ('Baker Analyzed' Reagent) in 1.4% v/v H_2SO_4 ('Baker Intra-Analyzed' Reagent), in deionized water (2 megaohm purity). This solution decomposed with time and was replaced every four hours.

When possible three extraction blanks were analyzed with each sample group. Sample triplicates and triplicate spikes were extracted and analyzed as 10% or more of sample load. The SRM (EPA Fish Tissue) and spiked blanks were also analyzed for mercury. Recoveries for SRM extractions are listed in Table 1b. Recoveries of 80% to 120% of expected value were regularly obtained for spiked blanks. Sample spike recoveries, however, tended to be erratic. For example, inclusion of the same sample in multiple extraction sets could yield spike recoveries as variable as 47% and 75% while mercury values for that same unspiked sample would remain consistent between sets. Nevertheless, we decided to include mercury values for samples with recoveries outside the normally accepted range (Appendix C) because both our spiked blank and SRM recoveries were within acceptable limits. Concentrations were not adjusted to spike recoveries.

Limits of Detection

It was necessary to establish a limit of detection for each element based upon the affects of our extraction procedures. We examined the concentration of the blanks accompanying each batch of tissue extractions to determine the level of background "noise". The standard deviation of the blanks is used as the measure of variability among replicate blank determinations for each element within an extraction batch. The means and standard deviations of extraction group blanks' are listed in Tables 2a and 2b. The minimum detection limit for each extraction set was set at three times the standard deviation of the blanks for each element (Table 3). The standard deviation can be multiplied by ten to obtain the limit of quantitation as defined by Keith et al. (1983).

Table 1b: Analyses of EPA Standard Reference Material

Water Pollution Quality Control Samples
mercury in Fish
(μg/g dry wt.)

Analysis Number	mean	standard deviation	Analysis Number	mean	standard deviation
1	3.03		6	1.90	
2	1.76		7	2.98	0.35
3	3.02		8	2.76	0.24
4	2.37		9	3.28	0.10
5	2.50				

Reference Values
Mean 2.52
Range 1.24 - 3.80

Table 2a. Mean and standard deviation of sample blanks
(μg/g wet wt.)

Extraction Set	Cd	Cr	Cu	Pb	Zn
A	0.000 0.000/2	0.03 0.04/2	0.10 0.04/5	0.15 0.00/2	0.28 0.18/2
B	0.000 0.000/2	—	0.04 0.00/2	0.30 0.00/2	0.65 0.14/2
C	0.000 0.000/3	0.04 0.00/2	0.05 0.00/4	0.10 0.00/2	0.15 0.14/2
D	0.008 0.00/2	0.15 0.00/2	0.03 0.04/2	0.23 0.04/2	—
E	—	0.23 0.00/2	0.05 0.00/2	—	0.05 0.07/3
F	--	0.23 0.00/2	0.00 0.00/5	0.13 0.04/2	0.05 0.07/3
G	0.003 0.004/2	—	—	0.10 0.07/2	0.03 0.04/2
H	—	—	—	0.10 0.00/2	—
I	—	—	—	0.00 0.07/2	—
J	0.005 0.006/5	0.20 0.00/6	0.03 0.03/6	0.28 0.18/7	0.06 0.05/7
K	0.019 0.009/4	0.10 0.00/4	0.00 0.00/4	0.01 0.23/4	0.18 0.07/4
L	0.000 0.006/5	0.13 0.03/5	0.09 0.03/4	0.07 0.07/5	0.04 0.04/5
M	0.003 0.005/6	0.03 0.03/6	0.00 0.03/9	0.50 0.06/9	0.09 0.03/9
N	0.004 0.004/6	0.02 0.03/9	0.00 0.00/9	0.10 0.10/14	0.010 0.02/9
O	0.020 0.010/6	0.03 0.03/6	0.08 0.03/6	0.19 0.24/7	0.00 0.03/7

Table 2a. (continued)

Extraction Set	Cd	Cr	Cu	Pb	Zn
P	0.010 0.005/9	0.04 0.02/12	0.07 0.05/15	0.07 0.09/9	0.08 0.06/9
Q			0.03 0.03/6		

Note: Table values follow this format: $\frac{\text{Mean}}{\text{Standard Deviation / n}}$

Mean = mean of blanks
Standard deviation = standard deviation of blanks
n = Number of times blanks were read for each extraction set

Table 2b. Mean, standard deviation and limit of detection of mercury samples (μg/g wet wt.)

Extraction Set	Mean/n	Standard Deviation	Limit of Detection
1	0.003/2	0.002	0.006
2	0.003/2	0.000	0.000
3	0.000/12	0.001	0.002
4	0.001/4	0.007	0.021
5	0.001/4	0.002	0.005
6	0.003/4	0.001	0.004
7	0.003/3	0.002	0.005
8	0.001/5	0.006	0.018
9	0.004/3	0.002	0.006
10	0.002/4	0.004	0.012
11	0.003/3	0.003	0.008
12	0.002/3	0.004	0.011
13	0.000/6	0.003	0.009
14	0.003/6	0.003	0.008

Note: n = Number of blanks for each extraction set

Table 3. Sample digestion detection limits
(μg/g wet wt.)

Extraction Set	Cd	Cr	Cu	Pb	Zn
A	0.000	0.01	0.00	0.00	0.53
B	0.000	0.01	0.01	0.00	0.42
C	0.000	0.01	0.00	0.00	0.42
D	0.011	0.01	0.11	0.11	0.21
E	0.011	0.00	0.00	0.11	0.21
F	0.011	0.01	0.00	0.11	0.21
G	0.011	0.01	0.08	0.21	0.11
H	0.011	0.01	0.08	0.00	0.11
I	0.025	0.01	0.08	0.21	0.11
J	0.018	0.00	0.08	0.54	0.15
K	0.025	0.00	0.00	0.68	0.20
L	0.017	0.08	0.08	0.20	0.12
M	0.015	0.08	0.08	0.17	0.10
N	0.011	0.08	0.00	0.30	0.06
O	0.029	0.08	0.08	0.72	0.09
P	0.015	0.06	0.15	0.27	0.17
Q			0.08		

Tests of Significance and Data Comparisons

A one-way Analysis of Variance (ANOVA) (NH Software, Inc.) was used to help discern spatial and temporal differences in the data. Mean metal concentrations below the limit of detection were assumed to be zero for the ANOVA in accordance with the National Status and Trends Mussel Watch Program (NOAA, 1989). Data sets with large numbers of undetectable values may have group mean concentrations below the limit of detection. All comparisons accepted by the computer program were tested with the ANOVA. Bartlett's test for homogeneity of group variances was also determined. Data sets containing a large proportion of trace metal concentrations below the limit of detection and/or small numbers of replicate determinations that were rejected by the computer program are indicated in the ANOVA summary figures. Lobster and winter flounder spatial, seasonal, and yearly analyses were computed when possible. Since none of the four bivalve species analyzed were indigenous to both harbor and coastal locations, ANOVA comparisons were different than those for lobster and flounder. Interharbor trace metal comparisons were based upon the softshell clams. Interspecies comparisons were determined instead of harbor versus coastal comparisons. Intraharbor and temporal comparisons were not possible due to the lack of replicates. ANOVA comparisons were considered to be significantly different at $p < 0.05$. All results of the ANOVA comparisons are included in this report and are presented in two-way matrix figures within the text.

Data was also compared (nonstatistically) to previously published results for Massachusetts and other coastal and offshore areas of New England. In comparing our data to studies reporting metal concentrations as $\mu g/g$ dry weight, we assumed an 80% moisture content and noted this conversion accordingly. Sedimentary metal levels from the NOAA (1988) report were used as guidelines to the relative environmental conditions for each sampling region. Metal concentrations in $\mu g/g$ wet wt., i.e. parts per million (ppm) for individual samples are provided in Appendix C, and station means and standard deviations are found in Appendix D. Station latitude and longitude coordinates are listed in Appendix E.

RESULTS AND DISCUSSION

Bivalve Species

Bivalve mollusc species were represented by the softshell clam, *Mya arenaria*, surf clam, *Spisula solidissima*, blue mussel, *Mytilis edulis*, and ocean quahog, *Arctica islandica*. Mean trace metal concentrations for bivalve species from coastal and harbor areas are listed in Table 4.

Cadmium: The range of cadmium concentrations for all bivalve samples was <0.020 ppm to 0.40 ppm. Softshell and surf clam contained very low mean cadmium concentrations, 0.036 ppm and 0.069 ppm in softshell clam and 0.042 ppm in surf clam (Table 4). Boston Harbor softshell clam had a very narrow range of concentrations, from 0.032 ppm to 0.039 ppm. Salem Harbor softshell clam exhibited a broader range of concentrations (0.044 ppm to 0.091 ppm) as did surf clam (<0.020 ppm to 0.07 ppm). Ocean quahog and blue mussel had four to five times more cadmium than softshell and surf clam (Figure 6), with means of 0.249 ppm (range: 0.214 ppm to 0.40 ppm) and 0.258 ppm (range: 0.180 ppm to 0.33 ppm) (Table 4), respectively. Differences in cadmium tissue levels appeared to reflect species variations since coastal bivalves had higher cadmium concentrations than harbor species which were exposed to potentially higher industrial cadmium inputs.

Cadmium concentrations in softshell clam were below the National Shellfish Sanitation Program (NSSP) Alert Level of 0.5 ppm (see Capuzzo et al., 1986). The mean cadmium level in Boston Harbor softshell clam (0.036 ppm) was similar to the mean concentration of 0.060 ppm reported by Wallace et al. (1988). Values listed in Capuzzo et al. (1986) for coastal areas of Massachusetts were generally between 0.1 ppm and 0.8 ppm, but varied from 0.0 ppm to 10.0 ppm. The mean cadmium concentration reported by the U.S. Food and Drug Administration for Massachusetts softshell clam was 0.044 ppm and included samples from Boston Harbor (USFDA, 1988).

Surf clam contained relatively low concentrations of cadmium (<0.020 ppm to 0.07 ppm) compared to other studies. Hall et al. (1978) reported an average of 0.110 ppm in surf clam from Block Island Sound. Cadmium levels as high as 0.475 ppm were reported in surf clam from the Mid-Atlantic coastal region (Hall et al., 1978).

The range of cadmium concentrations in blue mussel was 0.18 ppm to 0.33 ppm

Table 4

Mean concentrations of trace elements (μg/g wet weight) for bivalve species including sample size (parentheses), standard deviation [brackets], and ranges.

	Cd	Cr	Cu	Hg	Pb	Zn
Surf Clam	0.034(7)	0.40(7)	1.74(7)	0.025(5)	0.07(7)	9.18(7)
	[0.025]	[0.29]	[1.32]	[0.031]	[0.10]	[3.57]
	<0.020-0.07	0.10-0.87	0.68-4.80	<0.008-0.083	<0.20-0.24	4.87-15.0
Blue Mussel	0.258(4)	0.44(4)	4.37(4)	0.008(2)	1.76(4)	22.7(4)
	[0.060]	[0.26]	[1.83]	[0.008]	[1.31]	[5.8]
	0.180-0.33	0.16-0.73	1.61-6.42	<0.008-0.016	0.31-3.38	13.3-27.7
Ocean Quahog	0.294(6)	0.66(7)	2.64(7)	0.038(4)	1.70(7)	10.4(6)
	[0.062]	[0.25]	[1.28]	[0.055]	[0.84]	[2.2]
	0.214-0.400	0.25-0.89	0.92-5.46	<0.008-0.133	0.53-3.46	7.75-14.3
Salem Soft-Shelled Clams	0.069(3)	0.78(3)	2.87(3)	0.023(3)	0.62(3)	13.6(3)
	[0.019]	[0.06]	[0.52]	[0.005]	[0.20]	[1.9]
	0.044-0.091	0.73-0.86	2.16-3.39	0.016-0.027	0.44-0.90	11.0-15.4
Boston Soft-Shelled Clams	0.036(3)	0.33(3)	5.12(3)	0.025(3)	0.64(3)	15.5(3)
	[0.003]	[0.11]	[0.61]	[0.002]	[0.49]	[1.0]
	0.032-0.039	0.19-0.47	4.40-5.90	0.022-0.026	<0.27-1.18	14.2-16.8

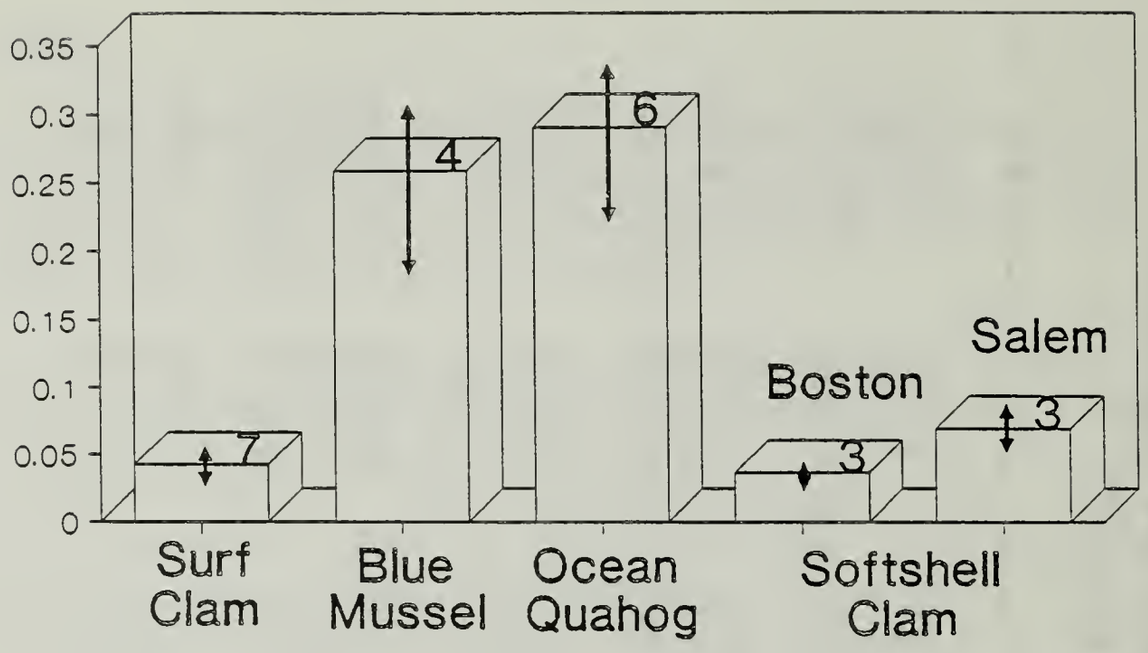


Figure 6. The bars represent the mean cadmium levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

and was similar to the range of 0.154 ppm to 0.518 ppm reported in Capuzzo et al. (1986). The National Status and Trends Program (NS&TP) mussel watch survey (NOAA, 1987) reported 0.20 ppm and 0.13 ppm (converted from dry wt. to wet wt.) for Boston Harbor and Buzzards Bay, respectively. In contrast, Greig and Sennefelder (1985) reported cadmium levels as high as 5.1 ppm in blue mussel near a Connecticut urban harbor in Long Island Sound.

Ocean quahog had the highest cadmium concentrations of all four bivalve species (mean: 0.294 ppm) (Figure 6). Steimle et al. (1986) reported cadmium levels from 0.27 ppm to 0.70 ppm (converted from dry wt. to wet wt.) for ocean quahog collected on Georges Bank and offshore areas of southern New England. Cadmium concentrations in Softshell clam from Salem and Boston Harbor were not significantly different (Figure 7) and were pooled for interspecies comparisons. The mean and variance of softshell clam cadmium content were not significantly different from those for surf clam (Figure 7). Softshell and surf clam means and variances were significantly different from those of blue mussel and ocean quahog, while blue mussel and ocean quahog were not significantly different (Figure 7). The softshell and surf clam mean cadmium levels were significantly lower than those for the blue mussel and ocean quahog. These patterns were at least partially influenced by species variations rather than cadmium input. For example, a NS&TP (NOAA, 1988) study found elevated levels of cadmium in Salem Harbor sediment compared to other locations and estuaries in the region. This elevated exposure was not reflected in the Salem Harbor softshell clam. In their review of contaminants in biota data, Capuzzo et al. (1986) found a similar situation with certain molluscs having relatively high metals values regardless of the environmental levels of metals.

Chromium: The range of chromium concentrations for all bivalve samples was 0.10 ppm to 0.89 ppm (Table 4). Boston Harbor softshell clam had the lowest mean chromium level (mean: 0.33 ppm, range 0.19 ppm to 0.47 ppm) while Salem Harbor had the highest mean of all molluscs (mean: 0.78 ppm, range 0.73 ppm to 0.86 ppm). Surf clam averaged 0.39 ppm (range: 0.10 ppm to 0.87 ppm), blue mussel had a slightly higher mean of 0.44 ppm chromium (range: 0.16 ppm to 0.73 ppm). Ocean quahog had the second highest mean chromium concentration, 0.66 ppm, with a range of 0.25 ppm to 0.89 ppm (Figure 8). All bivalve chromium levels were below the NSSP Alert Level of 1.0 ppm. Chromium concentrations in softshell clam listed in Capuzzo et al. (1986) were within the range of 0.0 ppm to 60.0 ppm. The higher levels (5.0 ppm to 60.0 ppm) came from Salem Harbor. Wallace et al. (1988) found higher levels of chromium in Boston Harbor softshell clam (0.44 ppm to 1.18 ppm) than detected in the

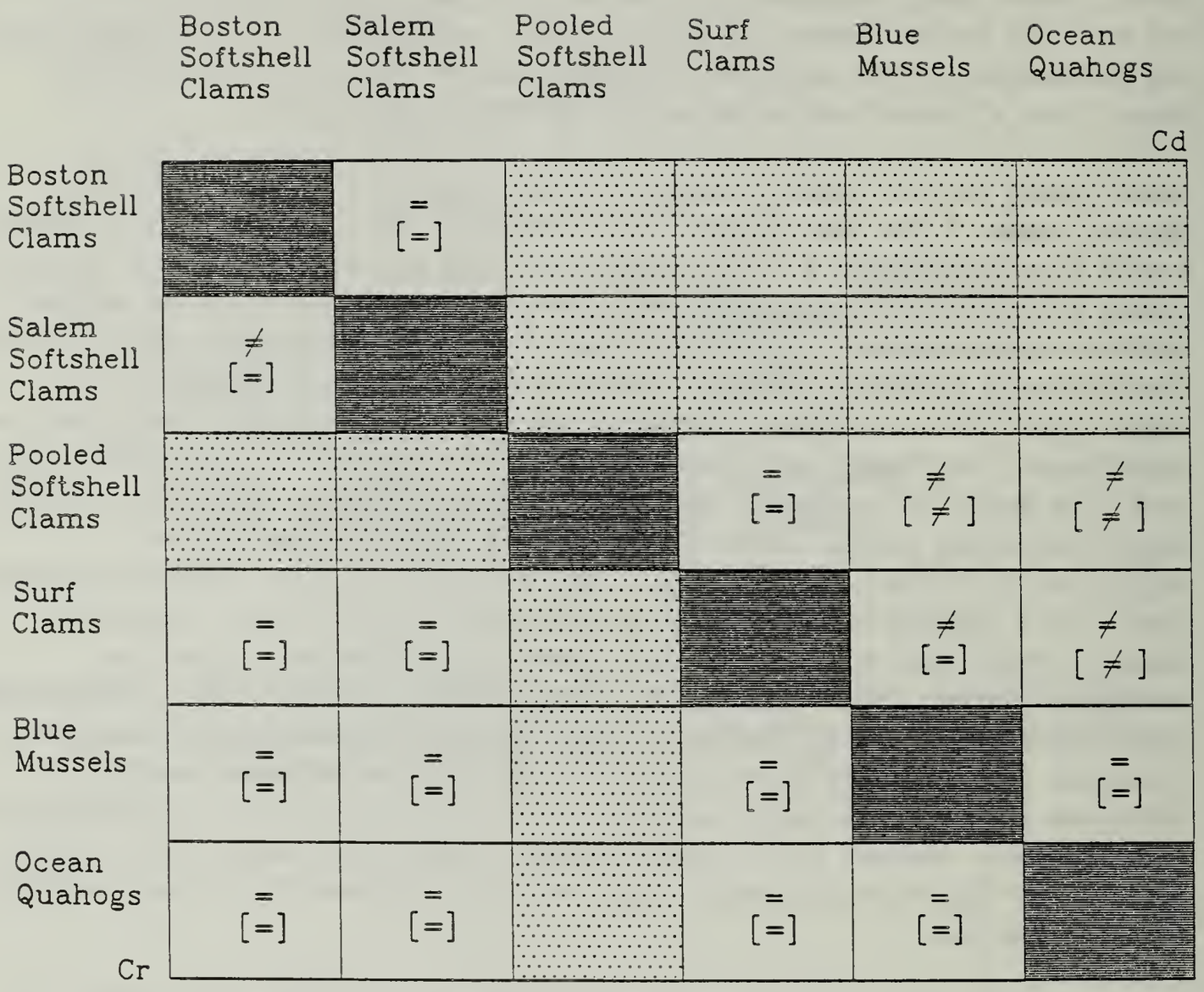


Figure 7. Summary of statistical analyses of shellfish cadmium and chromium means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by $\neq$ ($p<0.05$). Cadmium comparisons appear to the right of the diagonal, chromium to the left.

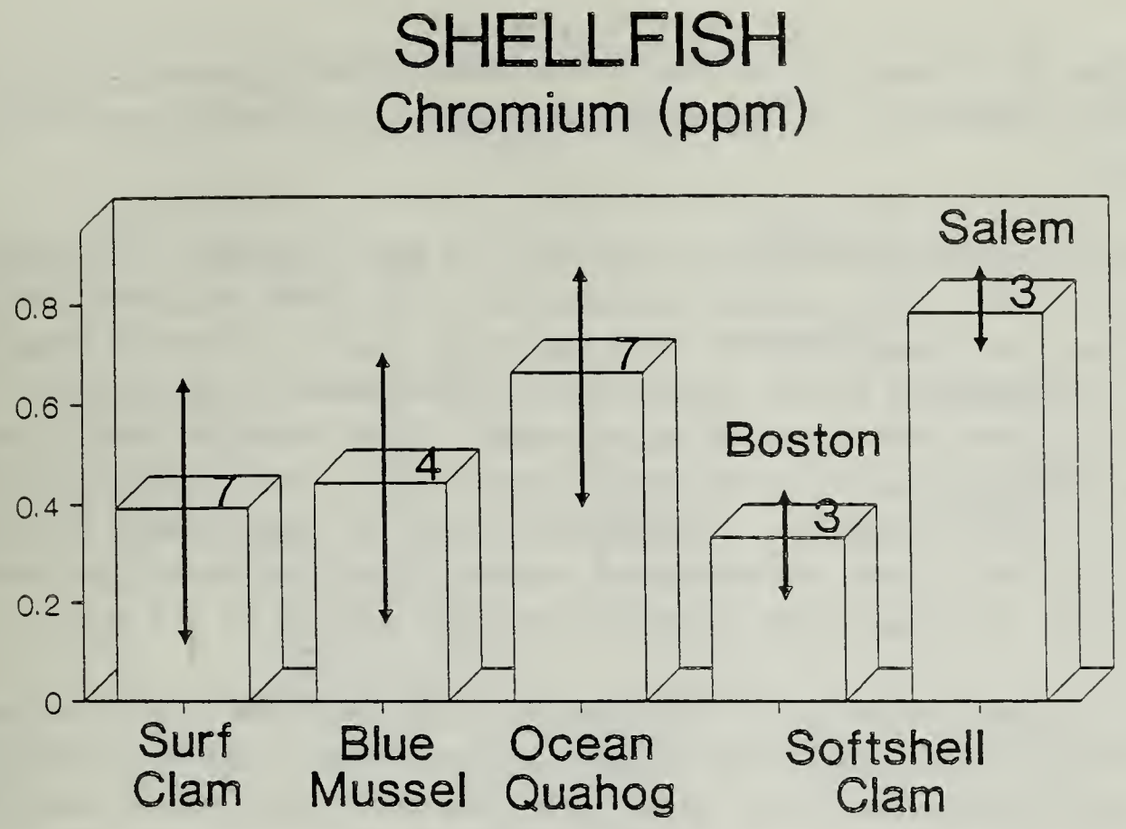


Figure 8. The bars represent the mean chromium levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

present study (0.19 ppm to 0.47 ppm). The mean chromium concentration for Massachusetts estuaries (including Boston Harbor) was 0.48 ppm according to USFDA (1988).

Blue mussel contained between 0.16 ppm and 0.73 ppm chromium. The NS&TP mussel watch (NOAA, 1987) and New England Aquarium (1988) reported similar concentrations for Boston Harbor (0.53 ppm to 0.47 ppm, converted from dry wt. to wet wt.). The NS&TP report noted that the blue mussel may have a particular affinity for accumulating chromium. High chromium levels in blue mussel near Salem Harbor (2.8 ppm to 4.0 ppm) were listed in Capuzzo et al. (1986) which further suggests preferential uptake of this element by the mussels and/or additional environmental inputs. These authors also reported chromium levels in Long Island Sound blue mussel as high as 7.0 ppm.

Surf clam contained between 0.10 ppm and 0.87 ppm chromium, and ocean quahog contained between 0.25 ppm and 0.89 ppm chromium. The range of chromium levels in surf clam from Block Island Sound was 0.51 ppm to 0.72 ppm with an average of 0.64 ppm (Hall et al., 1978). Chromium concentrations between 0.44 ppm and 0.61 ppm (converted from dry wt. to wet wt.) were reported for ocean quahog by Steimle et al. (1986) from Georges Bank and offshore areas of southern New England.

Salem Harbor softshell clam had a significantly higher mean chromium concentration compared to Boston Harbor softshell clam (Figure 7). This suggested exposure to additional chromium resulting from industrial processes, such as tanneries, which have been located in the Salem area. This was also reflected in the NS&TP sediment survey (NOAA, 1988) which reported very high levels of chromium in Salem Harbor sediment (3373.99 ppm dry wt.) compared to Boston Harbor sediment (260.87 ppm to 419.3 ppm dry wt.). All other bivalve ANOVA comparisons were not significantly different (Figure 7).

Copper: There was approximately an order of magnitude variation in the range of copper concentrations (0.68 ppm to 6.42 ppm) for all four bivalve species (Table 4). Boston Harbor softshell clam had a mean of 5.12 ppm copper (range 4.40 ppm to 5.90 ppm). The Salem Harbor softshell clam mean was much lower, 2.87 ppm (range: 2.16 ppm to 3.39 ppm). Surf clam contained between 0.68 ppm and 4.80 ppm copper (mean: 1.93 ppm). Blue mussel exhibited a wider range of values, 1.61 ppm to 6.42 ppm, with a mean of 4.27 ppm. The mean concentration for ocean quahog was 2.64 ppm copper, the range was 0.92 ppm to 5.46 ppm (Figure 9). All softshell clam copper concentrations were within the range of concentrations previously reported in Capuzzo et al. (1986) (2.8 ppm to 84

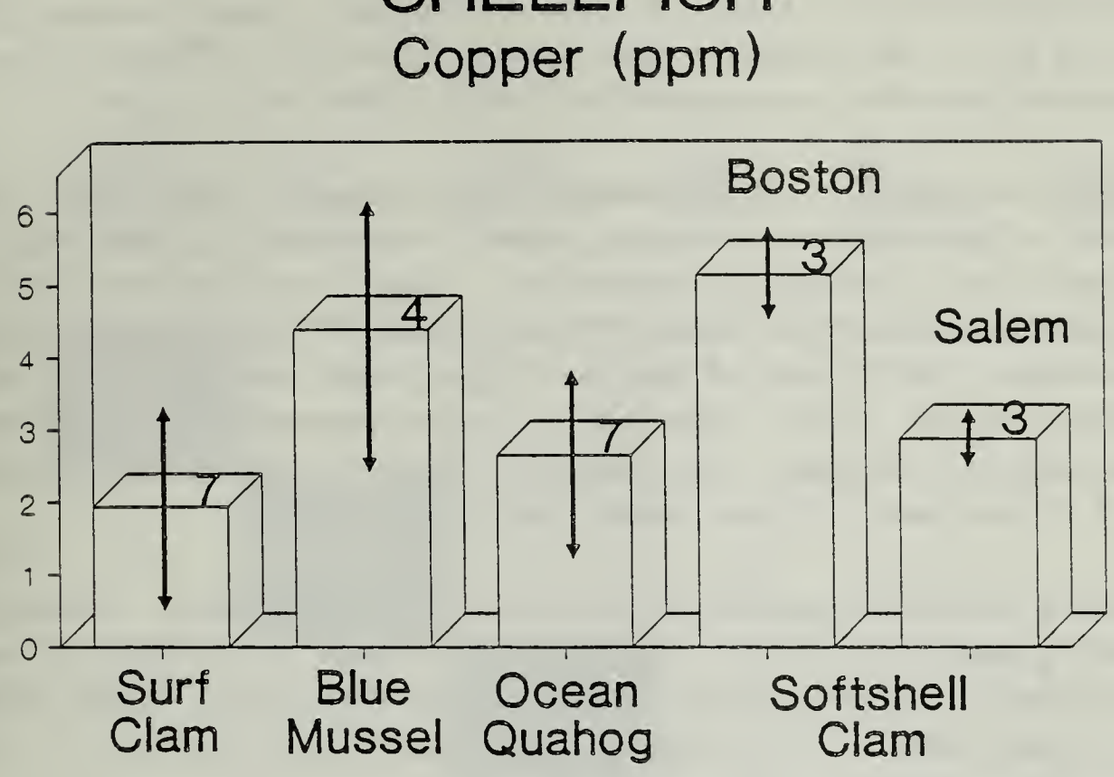


Figure 9. The bars represent the mean copper levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

ppm) and Wallace et al. (1988) (3.6 ppm to 9.0 ppm), and below the NSSP Alert Level of 25 ppm. The average copper concentration for softshell clam from Massachusetts estuaries as reported by USFDA (1988) was 4.1 ppm.

Blue mussel had between 1.60 ppm and 6.42 ppm copper. The highest copper concentration was observed in Spring, 1984. Unfortunately, the sample size was too small for statistical comparisons. Copper concentrations were similar to previously reported blue mussel tissue levels of 1.0 ppm to 2.3 ppm (Grieg and Sennefelder, 1985) and 0.0 ppm to 4.9 ppm, with one high value of 171.2 ppm (Capuzzo et al., 1986). The range of copper concentrations in the surf clam was 0.68 to 4.80 ppm. Surf clam from Block Island Sound contained between 3.31 ppm and 1.57 ppm copper (Hall et al., 1978).

Ocean quahog contained between 0.92 ppm and 5.46 ppm copper. The majority of ocean quahog samples were less than 2.80 ppm copper. The range of copper concentrations in ocean quahog collected by Steimle et al. (1986) from Georges Bank, Nantucket Shoals, and Southern New England was 1.3 ppm to 2.6 ppm (converted from dry wt. to wet. wt.).

Boston Harbor softshell clam had copper concentrations which were significantly higher than concentrations in Salem Harbor softshell clam, surf clam, and ocean quahog. Boston Harbor softshell clam were not significantly different from the blue mussel (Figure 10). There were no significant differences in copper levels between Salem Harbor softshell clam, surf clam, blue mussel, and ocean quahog. Ocean quahog were not significantly different from either surf clam or blue mussel, but blue mussel contained more copper than surf clam (Figure 10). Copper values in these samples appeared to be affected by both species and environmental effects. Blue mussel had significantly more copper than surf clam, even though both species were obtained from coastal locations. Capuzzo et al. (1986) and the NS&TP mussel watch program (NOAA, 1987) found that metals concentrations were frequently highest in a particular mollusc species. This occurred even when these samples were compared to other species collected from environments with higher metal concentrations. Possible environmental effects could be seen in the softshell clam data. Boston Harbor softshell clam had elevated copper levels compared to Salem Harbor softshell clam. This may reflect the higher copper concentrations in Boston Harbor sediments compared to Salem Harbor sediments as reported in the NS&TP sediment survey (NOAA, 1988).

Mercury: The range of mercury concentrations for all bivalve species was from below 0.008 ppm to 0.133 ppm (Table 4). All mercury levels were below

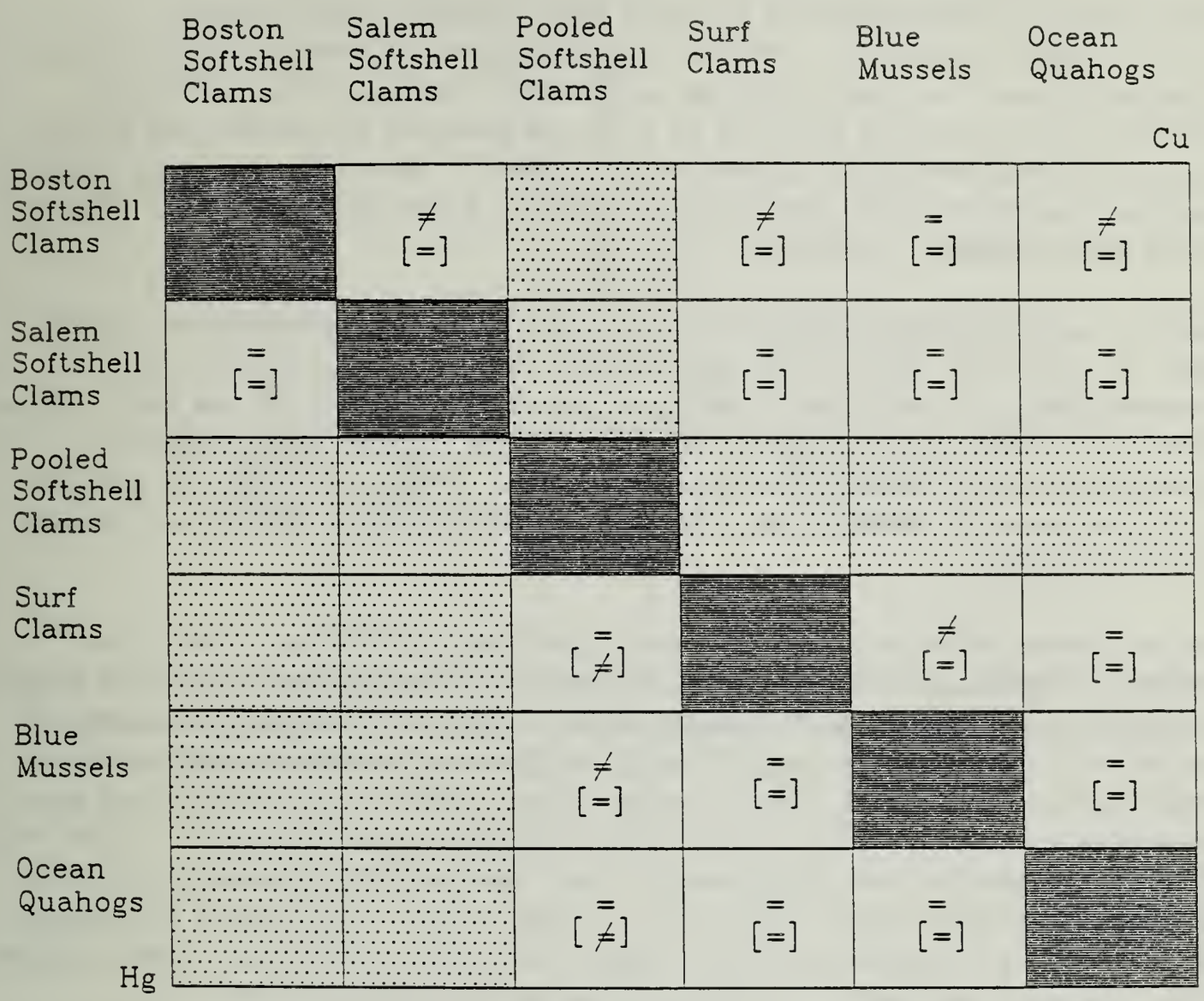


Figure 10. Summary of statistical analyses of shellfish copper and mercury means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Copper comparisons appear to the right of the diagonal, mercury to the left.

the 1.00 ppm Action Level established by the U.S. Food and Drug Administration. Boston Harbor softshell clam had a mean of 0.025 ppm mercury (range: 0.022 ppm to 0.026 ppm). Salem Harbor softshell clam had a similar mean mercury concentration (0.023 ppm) but a slightly wider range (0.016 ppm to 0.027 ppm) (Figure 11). Mercury concentrations in Boston Harbor softshell clam were lower than the 0.053 ppm reported by (Wallace et al., 1988) but similar to the range of 0.01 ppm to 0.04 ppm reported for harbor and coastal areas of Massachusetts in Capuzzo et al. (1986). The two blue mussel samples analyzed contained 0.016 ppm and less than 0.008 ppm mercury, with a mean of 0.008 ppm mercury.

Mercury concentrations in the surf clam varied from below detection (0.008 ppm) to 0.083 ppm (mean: 0.022 ppm) (Table 4). The range of mercury concentrations in surf clam from Block Island Sound was 0.020 ppm to 0.050 ppm with an average of 0.037 ppm (Hall et al., 1978). Ocean quahog samples contained mercury levels from below our limits of detection (<0.008 ppm) to 0.133 ppm mercury (mean: 0.040 ppm) (Table 4) with three of the four samples below 0.020 ppm.

Boston Harbor softshell clam were not significantly different from Salem Harbor softshell clam (Figure 10). Mercury data from these two harbors were pooled for comparisons to the other species. The mean mercury concentration in softshell clam was not significantly different from that in surf clam or ocean quahog. Both surf clam and ocean quahog exhibited variances that were significantly different from that of the softshell clam (Figure 10). The two blue mussel samples had significantly lower mean mercury concentrations than the pooled softshell clam (Figure 10). There were no significant differences in the means and variances of surf clam, blue mussel, and ocean quahog (Figure 10). The various levels of mercury found in these bivalves were not reflective of sediment mercury concentrations. The NS&TP sediment survey (NOAA, 1988) found mercury levels in Salem Harbor that were twice as high as Boston Harbor and six times the level in coastal sediments obtained near Cape Ann, Massachusetts.

Lead: Lead concentrations in bivalves (Figure 12) varied between the limit of detection (<0.20 ppm) and 3.46 ppm (Table 4). The range of lead concentrations in softshell clam from Boston Harbor was <0.27 ppm to 1.18 ppm (mean: 0.64 ppm). Salem Harbor softshell clam had a mean of 0.62 ppm lead (Table 4) with a range of 0.44 ppm to 0.90 ppm. Capuzzo et al. (1986) presented lead concentrations for coastal Massachusetts and Boston Harbor between 0.56 ppm and 5.2 ppm, but one data set for Salem Harbor contained

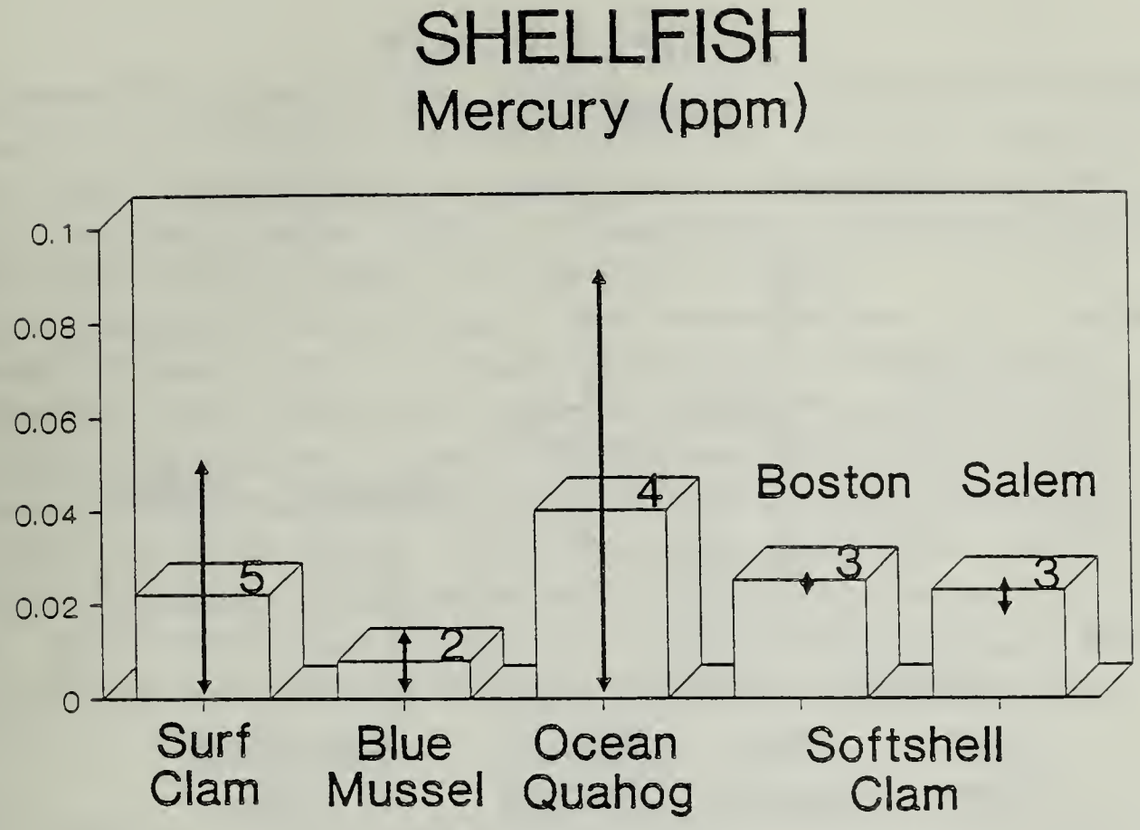


Figure 11. The bars represent the mean mercury levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

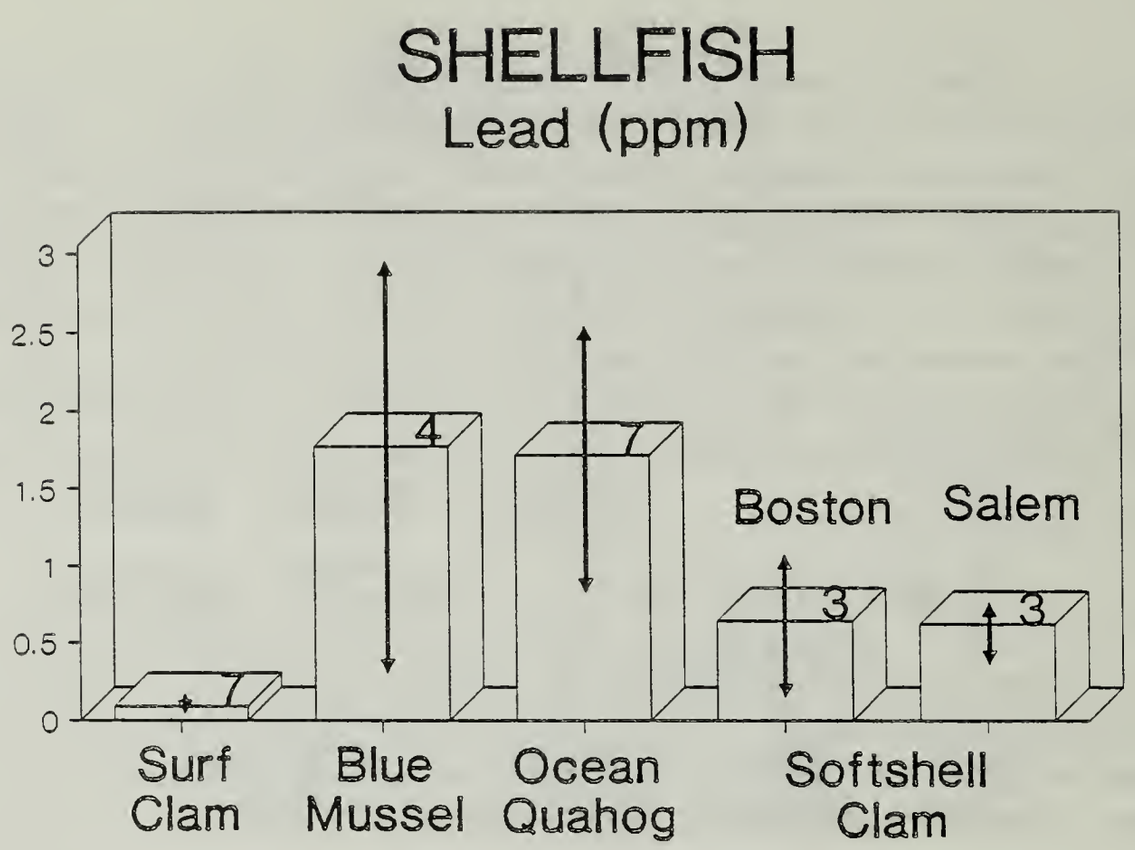


Figure 12. The bars represent the mean lead levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

levels between 15 ppm and 88 ppm. Wallace et al. (1988) reported a mean lead concentration of 1.37 ppm (range: 0.91 ppm to 2.76 ppm) for Boston Harbor softshell clam. The mean lead concentration for Massachusetts estuaries was 0.43 ppm according to USFDA (1988). All softshell clam samples had lead concentrations below the NSSP Alert Level of 5.0 ppm.
Blue mussel exhibited a wide range of lead concentrations (<0.31 ppm to 3.38 ppm, mean: 1.76 ppm , Table 4). Higher levels were obtained near Salem/Marblehead and lower levels South of Cape Cod. Capuzzo et al. (1986) listed lead concentrations between 0.574 ppm and 2.184 ppm in coastal Massachusetts (including Boston Harbor) and from 0.0 ppm to 2.31 ppm in blue mussel from Long Island Sound. The NS&TP Mussel Watch (NOAA, 1987) noted that blue mussel may possess a particular affinity for accumulating lead in tissues. They reported blue mussel lead concentrations from 0.89 ppm to 2.60 ppm for Boston Harbor and 0.69 ppm to 0.92 ppm for Buzzards Bay (converted from dry wt. to wet wt.).

Surf clam samples contained lead concentrations from below our limit of detection (<0.20 ppm) to 0.24 ppm, with a mean of 0.09 ppm (Table 4). In contrast, the range of lead concentrations in surf clam from Block Island Sound was 0.875 ppm to 1.250 ppm with a mean concentration of 1.096 ppm (Hall et al., 1978).

The range of lead concentrations in ocean quahog was 0.53 ppm to 3.46 ppm, and five of the seven station averages were between 1.00 ppm and 2.00 ppm. The single specimen with 3.46 ppm lead was obtained near Plymouth in Fall, 1984, and a sample obtained the following Spring, 1985, from the same area contained 1.70 ppm lead. Our ocean quahog sample size was very limited but may indicate a seasonal variation in lead concentration similar to that reported for Boston Harbor softshell clam by Wallace et al. (1988). The two lowest lead concentrations were found in ocean quahog from east of Cape Cod. Lead concentrations reported by Steimle et al. (1986) for ocean quahog from Georges Bank, Nantucket, and southern New England varied between 0.60 ppm and 2.21 ppm (converted from dry wt. to wet wt.).

The means and variances of the softshell clam from Boston and Salem Harbors were not significantly different (Figure 13) and were pooled for interspecies comparisons. Softshell clam had a significantly higher mean lead concentration and larger variance than surf clam. The mean lead concentration for softshell clam was not significantly different from that of blue mussel (Figure 13), even though the blue mussel mean lead concentration was three times that of softshell clam (Figure 12). The absence of a significant

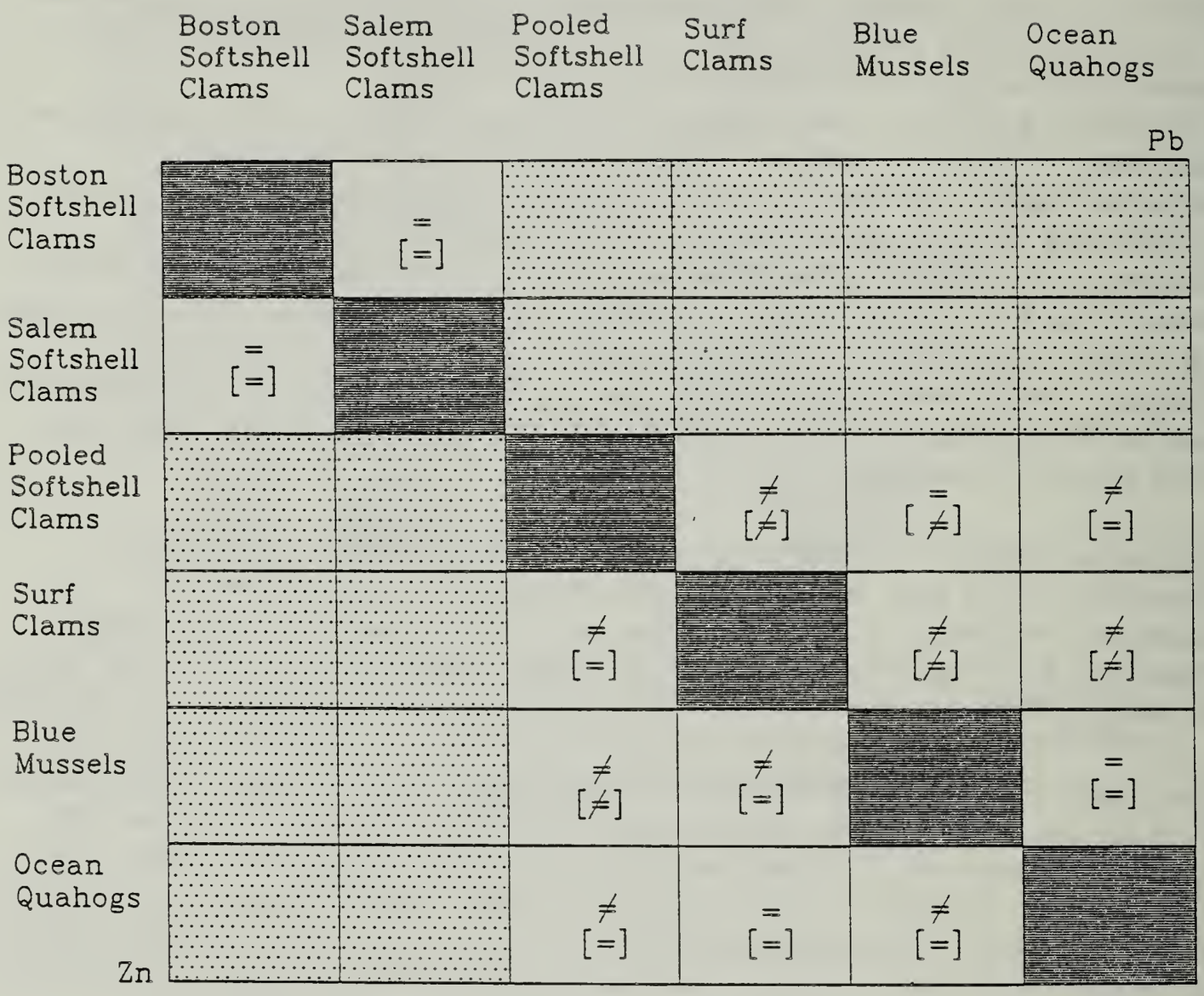


Figure 13. Summary of statistical analyses of shellfish lead and zinc means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Lead comparisons appear to the right of the diagonal, zinc to the left.

difference between these two species may be due to the significantly different variances of the two species groups. The standard deviation of blue mussel lead concentrations was three times that of softshell clam. Ocean quahog had significantly higher mean concentrations of lead than softshell clam, and the two groups had similar variances (Figure 13). Both mean lead concentration and group variance of surf clam were significantly lower than those of blue mussel and ocean quahog. No significant differences between means and variances were found when we compared blue mussel and ocean quahog. The relatively high lead concentrations in blue mussel and ocean quahog compared to softshell and surf clam demonstrated how interspecies differences affect metal uptake. Even though surf clam, blue mussel, and ocean quahog were all obtained from coastal areas, blue mussel and ocean quahog were found to contain twenty times the lead concentration in surf clam (Figure 12). The NS&TP Mussel Watch (NOAA 1987) reported that blue mussel may have an affinity for lead, and our data suggest this affinity for lead may also exist for ocean quahog. Additional species effects on metal uptake were seen when we compared softshell clam to blue mussel and ocean quahog. Softshell clam from the harbors had one-third the lead concentration in blue mussel and ocean quahog from coastal areas. In contrast, the NS&TP sediment survey (NOAA 1988) found lead concentrations in sediments from Boston and Salem Harbors that were approximately twice the concentration reported from a coastal location (Cape Ann, Massachusetts).

Zinc: The range of zinc concentrations for all bivalves was 4.87 ppm to 27.7 ppm (Table 4). We attribute the wide range to variations between species (Figure 14). Boston Harbor softshell clam contained between 14.2 ppm and 16.8 ppm zinc (mean: 15.5 ppm), Salem Harbor softshell clam between 11.0 ppm and 15.4 ppm (mean: 13.6 ppm) (Table 4). Both sets of clam data from the harbors were below the 30 ppm NSSP Alert Level. The mean zinc concentration in Boston Harbor softshell clam of 15.6 ppm was very similar to the mean of 15.5 ppm reported by Wallace et al. (1988) for this specie, and a mean of 15 ppm reported by USFDA (1988) for Massachusetts estuaries including Boston Harbor. DiGiulio and Scanlon (1985) reported zinc levels averaging 20 ppm in Chesapeake Bay softshell clam (converted from dry wt. to wet wt.)

Blue mussel had between 13.3 ppm and 27.7 ppm zinc (mean: 22.7 ppm) (Table 4), and three of the four concentrations exceeded 22 ppm. The sample with 13.3 ppm zinc was collected from south of Cape Cod. The NS&TP mussel watch (NOAA, 1987) reported an average zinc level in Boston Harbor and Buzzards Bay blue mussel of 25.7 ppm and 17.6 ppm, respectively (converted from dry wt. to wet

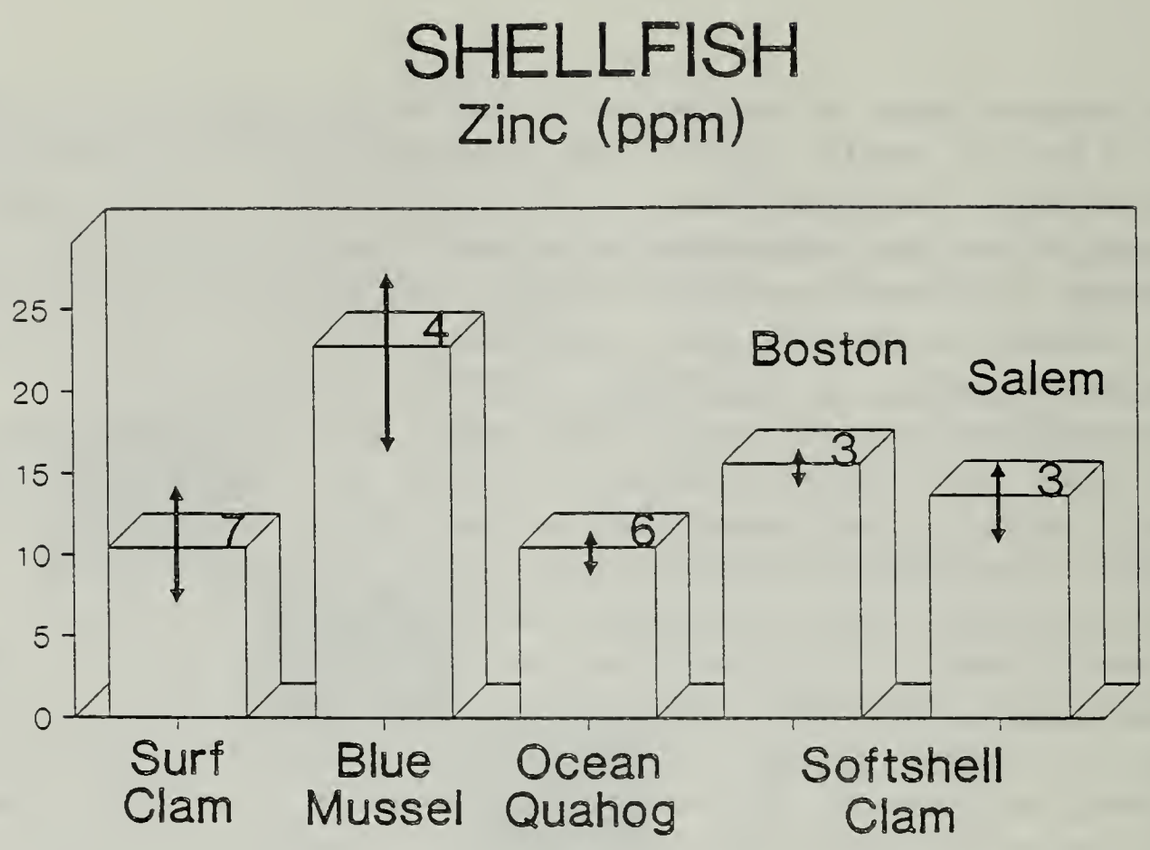


Figure 14. The bars represent the mean zinc levels, in ppm, for shellfish. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

wt.). Capuzzo et al. (1986) listed similar zinc concentrations for areas of Massachusetts and Rhode Island, and generally lower levels for Maine blue mussel. The New England Aquarium (1988) found a much wider range of zinc concentrations in blue mussel from Boston Harbor, 13 ppm to 53 ppm (converted from dry wt. to wet wt.). The range of zinc concentrations in surf clam was 4.87 ppm to 15.0 ppm (mean: 10.41 ppm) (Table 4). Hall et al. (1978) reported zinc concentrations in surf clam from Block Island Sound between 15.27 ppm and 18.75 ppm, with a mean concentration of 16.44 ppm. The range of zinc concentrations in ocean quahog in the present study was 7.75 ppm to 14.31 ppm (mean: 10.4 ppm) (Table 4). Steimle et al. (1986) reported zinc levels in ocean quahog from Georges Bank and offshore areas of southern New England that varied between 12.4 ppm and 30.8 ppm (converted from dry wt. to wet wt.).

Salem Harbor softshell clam were not significantly different from Boston Harbor softshell clam (Figure 13), and were pooled for comparison with other shellfish species. Softshell clam contained significantly less zinc than blue mussel but significantly more zinc than surf clam or ocean quahog. Blue mussel also contained significantly more zinc than either surf clam or ocean quahog (Figure 13). Surf clam and ocean quahog mean zinc concentrations were not significantly different.

American Lobster

Metal concentrations in composited lobster (*Homarus americanus*) tissues were compared to results from other studies. Previous studies reported metal concentrations for either muscle tissue or separately analyzed muscle tissue and tomalley (hepatopancreas) (Hall et al., 1978; Reid et el., 1982; Roberts et al., 1982; USEPA, 1988; Wallace et al., 1988). Therefore, direct comparisons with earlier reports were not always possible because of partitioning of metals between different tissue types. For example, a study of muscle and tomalley tissues from Boston Harbor lobster (USEPA, 1988) determined that cadmium, chromium, and copper were enriched in the tomalley (hepatopancreas) compared to muscle tissue. Conversely, this same study found that mercury concentrations in lobster muscle tissue were two-to-seven times higher than the tomalley, but that lead partitioned in roughly equal concentrations between the two tissues. Similar partitioning of metals between muscle and hepatopancreas was reported by the Connecticut Department of Environmental Protection (1987) for lobster from Long Island Sound. Mean trace metal concentrations for American lobster from coastal and harbor areas are listed in Table 5.

Table 5.

Mean concentrations of trace elements (μg/g wet weight)
for lobster samples including sample size (parentheses),
standard deviation [brackets], and ranges.

	Cd	Cr	Cu	Hg	Pb	Zn
Salem Harbor	0.211(19)	0.49(19)	20.9(19)	0.120(19)	0.04(19)	24.3(19)
	[0.163]	[0.35]	[4.05]	[0.046]	[0.07]	[4.6]
	0.048-0.474	0.10-1.24	13.3-28.6	0.059-0.228	0.03-0.23	15.4-34.8
Boston Harbor	0.153(14)	0.10(14)	26.9(14)	0.161(12)	0.23(14)	28.1(14)
	[0.087]	[0.09]	[8.99]	[0.029]	[0.24]	[3.7]
	<0.011-0.314	<0.06-0.30	17.8-43.2	0.113-0.214	<0.21-0.63	24.2-36.1
Coastal Mass.	0.355(22)	0.13(23)	30.8(23)	0.144(19)	0.07(23)	28.8(22)
	[0.187]	[0.08]	[9.4]	[0.058]	[0.11]	[7.8]
	0.102-0.831	0.04-0.38	18.0-56.8	0.052-0.289	<0.11-0.37	16.0-41.3

Cadmium: The range of cadmium concentrations in all lobster was from below 0.011 ppm to 0.831 ppm. Boston Harbor lobster contained <0.011 ppm to 0.314 ppm cadmium with a mean of 0.153 ppm (Table 5). The mean cadmium concentration in Salem Harbor lobster was 0.211 ppm (Table 5). The range for these samples was 0.048 ppm to 0.474 ppm. Coastal lobster, on average, contained more cadmium than lobster from Boston and Salem Harbor (Figure 15). The mean cadmium concentration in coastal lobster (0.355 ppm, range: 0.102 ppm to 0.831 ppm, Table 5) was similar to the range of levels found in lobster from Georges Bank and the outer continental shelf (0.070 ppm to 0.695 ppm) reported by Hall et al. (1978). The majority of lobster tail and claw meat analyses from all coastal areas of Northeastern United States contained cadmium levels between 0.2 ppm and 0.3 ppm, but body meat concentrations were reported as high as 14.880 ppm (Hall et al., 1978). The range of cadmium concentrations in lobster from Long Island Sound of 0.08 ppm to 0.12 ppm listed in Capuzzo et al. (1986) was lower than most of the samples in the present study. Lobster hepatopancreas (tomalley) has the capacity to sequester large concentrations of cadmium, which could influence total body burdens, but the role of metabolic processes in regulating cadmium concentrations is unclear (Engel and Brouwer, 1984).

One significant spatial and one significant seasonal difference were detected in the Salem Harbor lobster cadmium concentrations (Figure 16). Station S2 had more cadmium in the Spring than in the Fall and less cadmium than station S3 during December 1986. No other spatial or seasonal differences were found in the Salem Harbor samples. Lobster from Boston Harbor and coastal areas exhibited no spatial or seasonal differences in their cadmium content (Figure 16). Pooled Salem Harbor lobster did not contain significantly different mean cadmium concentrations when compared to pooled Boston Harbor and pooled coastal samples. Similar findings for cadmium levels in Boston and Salem Harbor lobster were reported by Wallace et al. (1988). Salem Harbor lobster had a significantly wider variance in cadmium concentration than Boston Harbor lobster (Figure 16). Lobster from Boston Harbor contained less cadmium and had a significantly smaller variance than lobster from the coastal area (Figure 16). The distribution of cadmium in lobster did not reflect the distribution of cadmium concentrations found in the sediments. The NS&TP sediment survey (NOAA, 1988) found very high concentrations of cadmium in Salem Harbor sediment (9.79 ppm dry wt.) compared to Boston Harbor (3.24 ppm dry wt.) and Cape Ann, Massachusetts (0.51 ppm dry wt.).

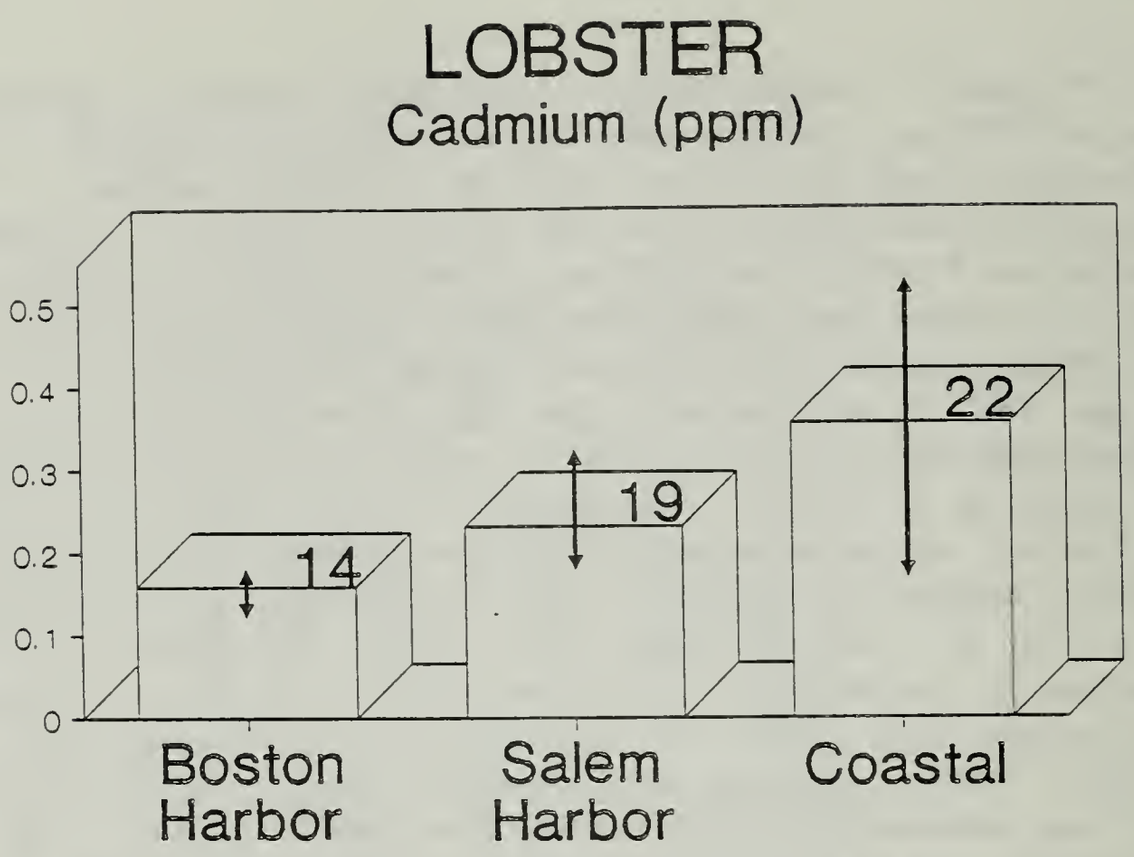
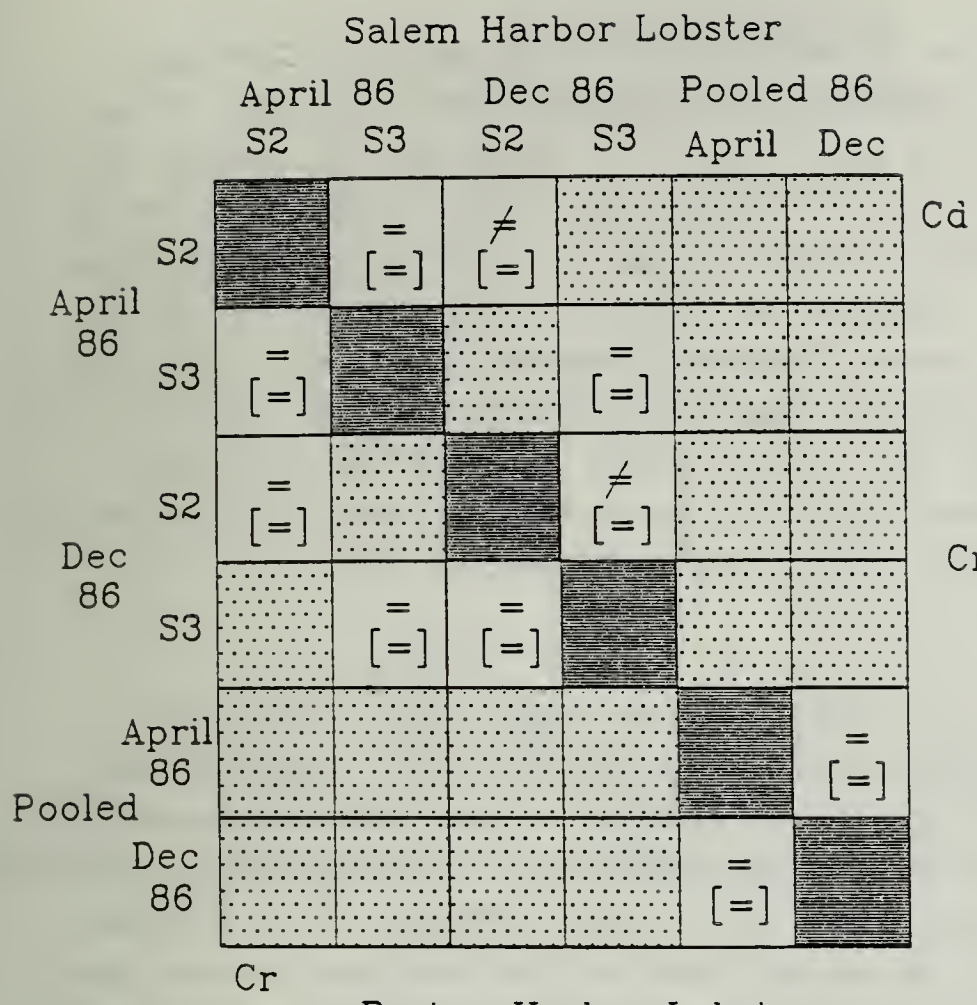
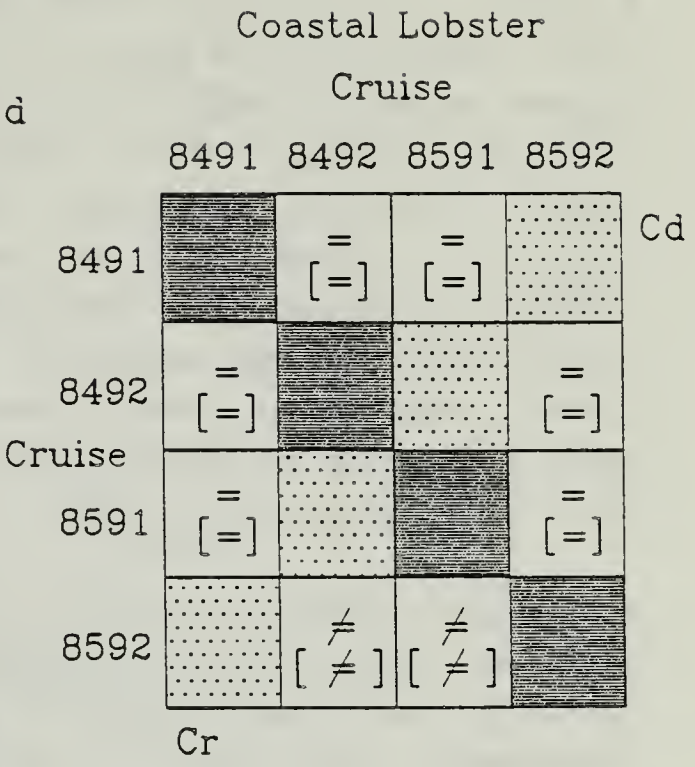


Figure 15. The bars represent the mean cadmium levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.





a) Variance of one of the two groups equals zero, variance comparison not possible.

Figure 16. Summary of statistical analyses of lobster cadmium and chromium means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by $\neq$ ($p<0.05$). Cadmium comparisons appear to the right of the diagonal, chromium to the left.

Chromium: The range of chromium concentrations in lobster was 0.04 ppm to 1.24 ppm. Lobster from Boston Harbor had a mean concentration of 0.10 ppm with a range of <0.06 ppm to 0.30 ppm (Table 5). Salem Harbor samples had the highest chromium levels of all lobster (Figure 17) with a range of 0.10 ppm to 1.24 ppm and a mean of 0.49 ppm chromium (Table 5). The range of chromium levels in coastal lobster was 0.04 ppm to 0.38 ppm with a mean of 0.13 ppm (Table 5). Boston Harbor and coastal lobster concentrations were similar to chromium concentrations reported for Long Island Sound lobster (range = 0.26 ppm to 0.50 ppm; see Capuzzo et al., 1986). Tail and claw meat (muscle tissue) from Georges Bank lobster typically contained between 0.1 ppm and 0.2 ppm chromium, but concentrations varied between 0.046 ppm and 0.690 ppm (Hall et al., 1978).

Salem Harbor samples exhibited no statistically significant spatial or seasonal differences in chromium concentration (Figure 16). Lobster from Boston Harbor demonstrated no significant spatial or intrastation seasonal difference. Pooled Boston Harbor samples collected in December 1986 contained significantly less chromium than April 1986 samples (Figure 16). However, this significant difference may be an artifact of the data set because April data were from only one station while December samples were obtained from all three stations. Coastal lobster samples from the Spring of 1984 (8491) were not significantly different from those obtained in the Fall of 1984 (8492) and Spring of 1985 (8591). Fall 1985 (8592) lobsters contained more chromium than those in the Fall of 1984 (8492) and Spring of 1985 (8591) (Figure 16). Salem Harbor lobster were significantly different from both Boston Harbor and coastal lobster (Figure 16). Wallace et al. (1988) did not report a significant difference in chromium concentration between Salem and Boston Harbor lobster. However, in the present study which is based on composite analysis of muscle and tomalley tissues Salem Harbor lobster contained four to five times more chromium and had a larger variance than either Boston Harbor or coastal lobster (Figure 16). Chromium concentrations in lobster from coastal areas of Massachusetts were not significantly different from Boston Harbor lobster (Figure 16). Pooled lobster data may reflect the sedimentary environmental conditions. For example, the National Status and Trends Program (NS&TP) sediment survey (NOAA, 1988) reported a chromium concentration in fine-grained sediment of Salem Harbor of 3373.98 ppm dry wt., while Boston Harbor contained between 260.87 ppm and 419.3 ppm dry wt. and a nearby coastal site (Cape Ann) contained 103.42 ppm dry wt. chromium. The high chromium levels we observed in Salem Harbor lobster and softshell clam were probably the result of exposure to large chromium concentrations in the sediment.

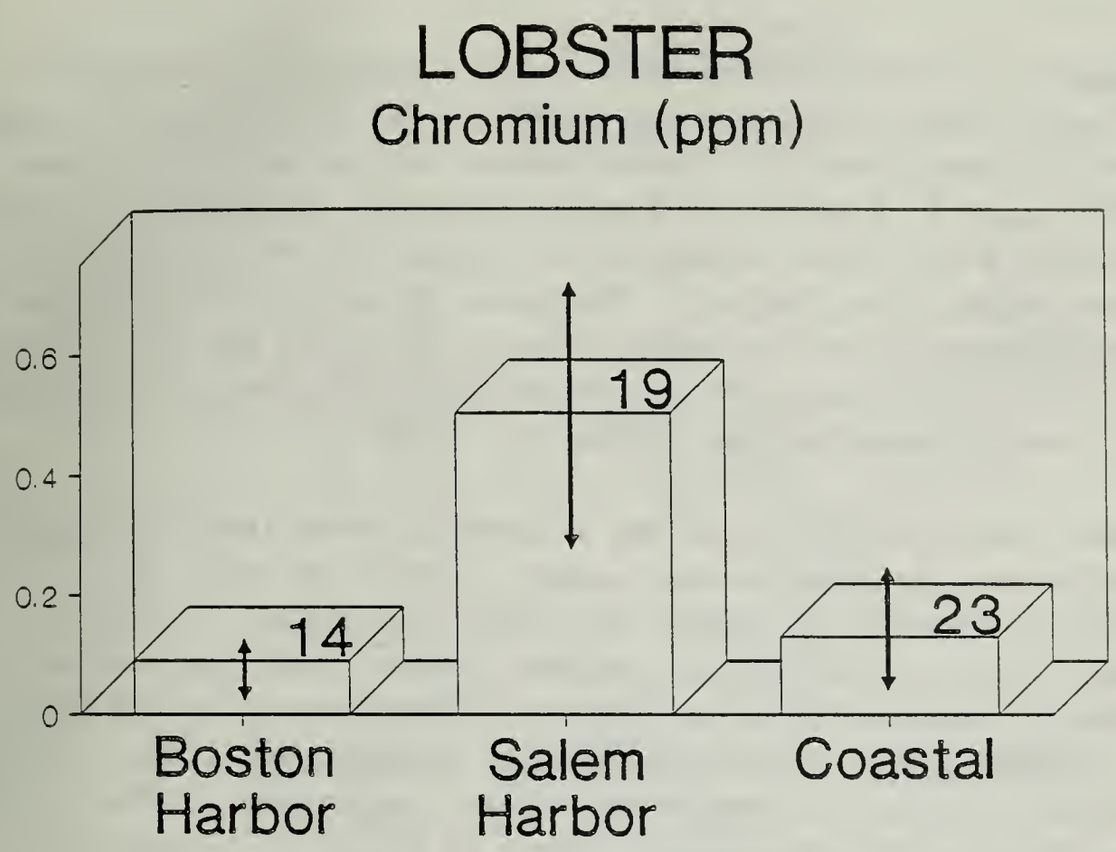


Figure 17. The bars represent the mean chromium levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

Copper: The range of copper concentrations in all lobster was 13.3 ppm to 56.8 ppm. The mean copper level in coastal lobster was 30.8 ppm and the range was 18.0 ppm to 56.8 ppm (Table 5). Boston Harbor lobster contained a mean of 26.9 ppm copper (range: 17.8 ppm to 43.2 ppm) (Table 5). Salem Harbor lobster contained the lowest mean copper concentration (Figure 18) of 20.9 ppm with a range of 13.3 ppm to 28.6 ppm (Table 5). The range of copper concentrations in lobster tail and claw meat from the North Atlantic was 5.750 ppm to 33.750 ppm (Hall et al., 1978), and the majority of lobster from all areas in the present study contained copper concentrations within this range.

Discerning between naturally occurring and industrial/urban levels of copper in lobster is often not possible because copper, as well as zinc, are essential biological elements in lobster and other crustaceans. Studies conducted on the blue crab, *Callinectes sapidus*, demonstrated that copper, zinc, and hemocyanin concentrations are affected significantly by the molt cycle, season and temperature (Engel, 1987; Engel and Brouwer, 1987). Since lobster also contain a metal-binding protein (Engel and Brouwer, 1984), it was not possible to distinguish anthropogenic inputs of copper in lobster from levels associated with physiological processes.

There were no significant differences in copper concentrations either spatially or on a station-to-station seasonal basis in Salem Harbor. Pooled seasonal data (April vs. December) indicated a significant difference between the two seasons with April lobster samples containing more copper than December lobster (Figure 19). Boston Harbor lobster exhibited no significant spatial or seasonal differences (Figure 19), similarly, no significant seasonal or yearly differences occurred in copper concentrations in coastal lobster (Figure 19). Boston Harbor and coastal lobster were not significantly different from each other but lobster from Salem Harbor contained a significantly lower copper concentration and smaller variance than lobster from other sites (Figure 19). This difference contrasted with relative copper concentrations in sediments reported by the NS&TP sediment survey (NOAA, 1988). NOAA found copper levels in Salem Harbor sediments four times higher than sediments from a nearby area of coastal Massachusetts (Cape Ann). Data from a previous study by Wallace et al. (1988) indicated that Boston Harbor lobster muscle tissue (mean: 14.4 ppm) was significantly higher in copper content than Salem Harbor lobster tissue (mean: 9.1 ppm).

Mercury: Lobster contained between 0.052 ppm and 0.289 ppm mercury which was below the USFDA action level of 1.00 pmm. There was very little difference

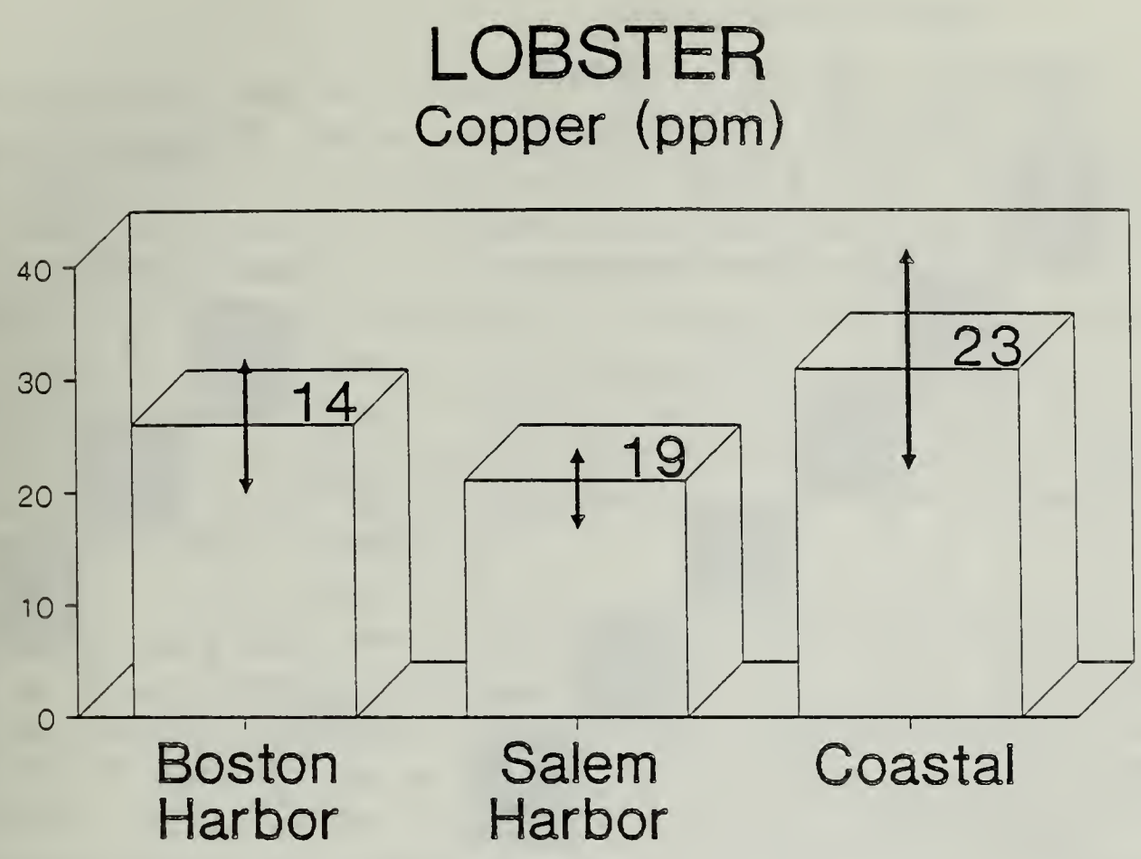


Figure 18. The bars represent the mean copper levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

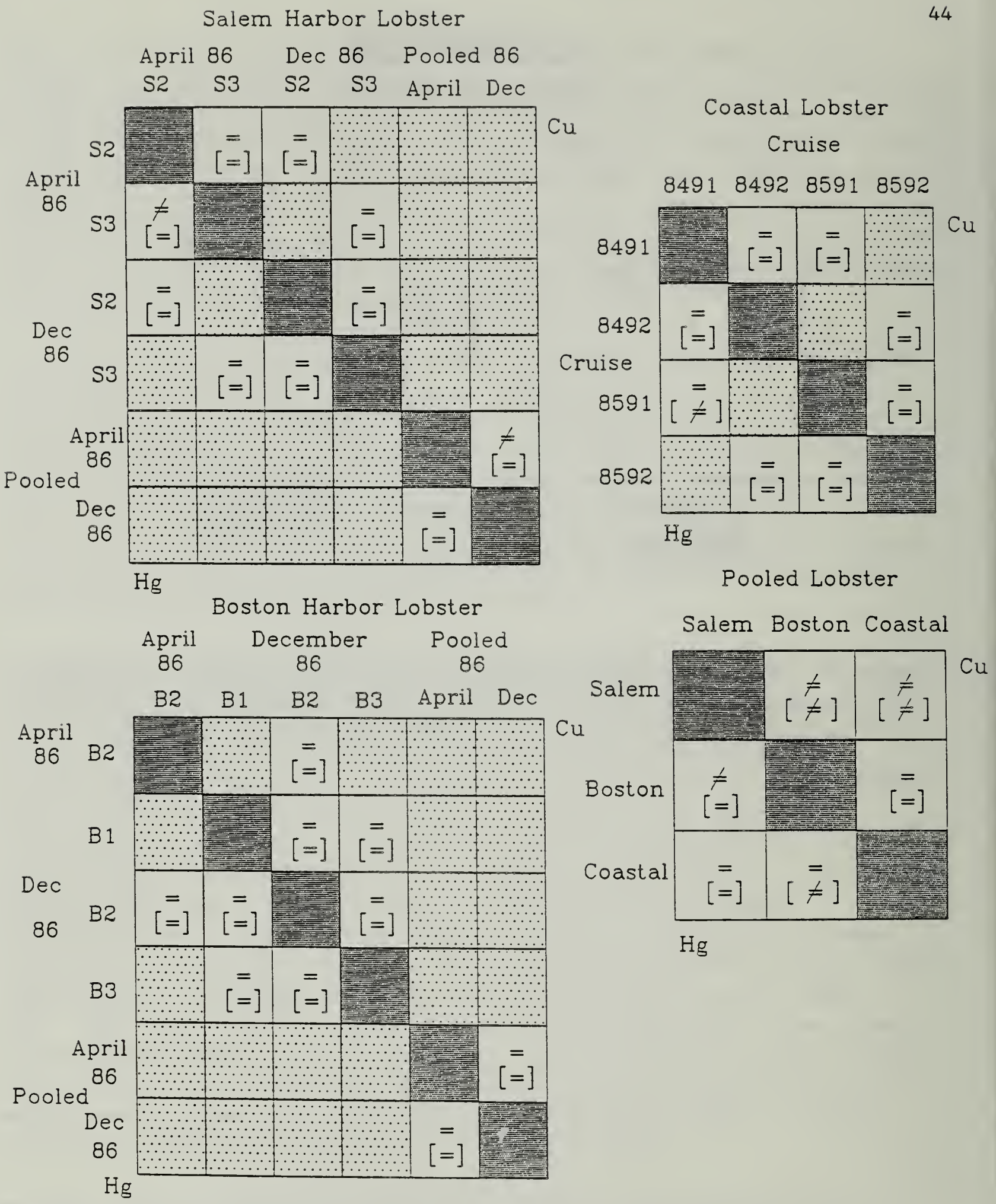


Figure 19. Summary of statistical analyses of lobster copper and mercury mean and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Copper comparisons appear to the right of the diagonal, mercury to the left.

between mean mercury concentrations (Figure 20) for coastal and harbor lobster. Salem Harbor lobster contained between 0.059 ppm and 0.228 ppm mercury with a mean of 0.120 ppm (Table 5). Boston Harbor lobster had the highest mean concentration, 0.161 ppm, with a range of 0.113 ppm to 0.214 ppm (Table 5). Mercury concentrations in coastal lobster ranged from 0.052 ppm to 0.289 ppm with a mean concentration of 0.144 ppm (Table 5). All mercury levels in our lobster samples were less than or equal to mercury concentrations found in lobster tail and claw meat from Georges Bank (Hall etal., 1978). Mean mercury levels in lobster tail and claw meat from Georges Bank were between 0.2 ppm and 0.3 ppm, but varied as high as 0.590 ppm or as low as 0.050 ppm (Hall et al. 1978).

Lobster from Salem Harbor station S2 contained significantly less mercury than station S3 in April 1986 but not in December 1986. No other significant spatial or seasonal differences occurred within the Salem Harbor lobster mercury data (Figure 19) and no significant differences were found within the Boston Harbor lobster mercury data set (Figure 19). Lobster obtained from coastal areas exhibited no seasonal or yearly difference in mean mercury concentrations but samples from Spring 1984 (cruise 8491) had a narrower variance than lobster from Spring 1985 (cruise 8591) (Figure 19). Boston Harbor lobster contained significantly more mercury than lobster from Salem Harbor. Wallace et al. (1988) reported that no significant difference existed in mercury levels between Boston and Salem Harbor lobster, but concluded that the size of the lobster affected mercury concentration. Although Boston Harbor and coastal lobster mean mercury levels were not significantly different, samples from coastal Massachusetts had a larger variance than those from Boston Harbor. Salem Harbor lobster were not significantly different from coastal lobster. In contrast, the NS&TP sediment survey (NOAA, 1988) found similar mercury levels in Boston and Salem Harbors sediment (1.7 ppm dry wt.) while a sediment sample near Cape Ann, Massachusetts contained only one-seventh the concentration of mercury (0.25 ppm dry wt.).

Lead: The range of lead concentrations in lobster was 0.03 ppm to 0.63 ppm. The highest mean lead concentration was found in Boston Harbor lobster (0.23 ppm, range: <0.21 ppm to 0.63 ppm). Salem Harbor lobster had the lowest mean lead concentration (0.04 ppm, range: 0.03 ppm to 0.23 ppm) (Figure 21). Lobster from coastal areas had lead values which ranged from <0.11 ppm to 0.37 ppm with a mean of 0.07 ppm (Table 5). Many of the lead concentrations in our lobster samples were below our limits of detection which affected our calculated mean lead concentrations. Most of the lead concentrations in lobster tail and claw meat from Georges Bank were between 0.5 ppm and 0.6 ppm

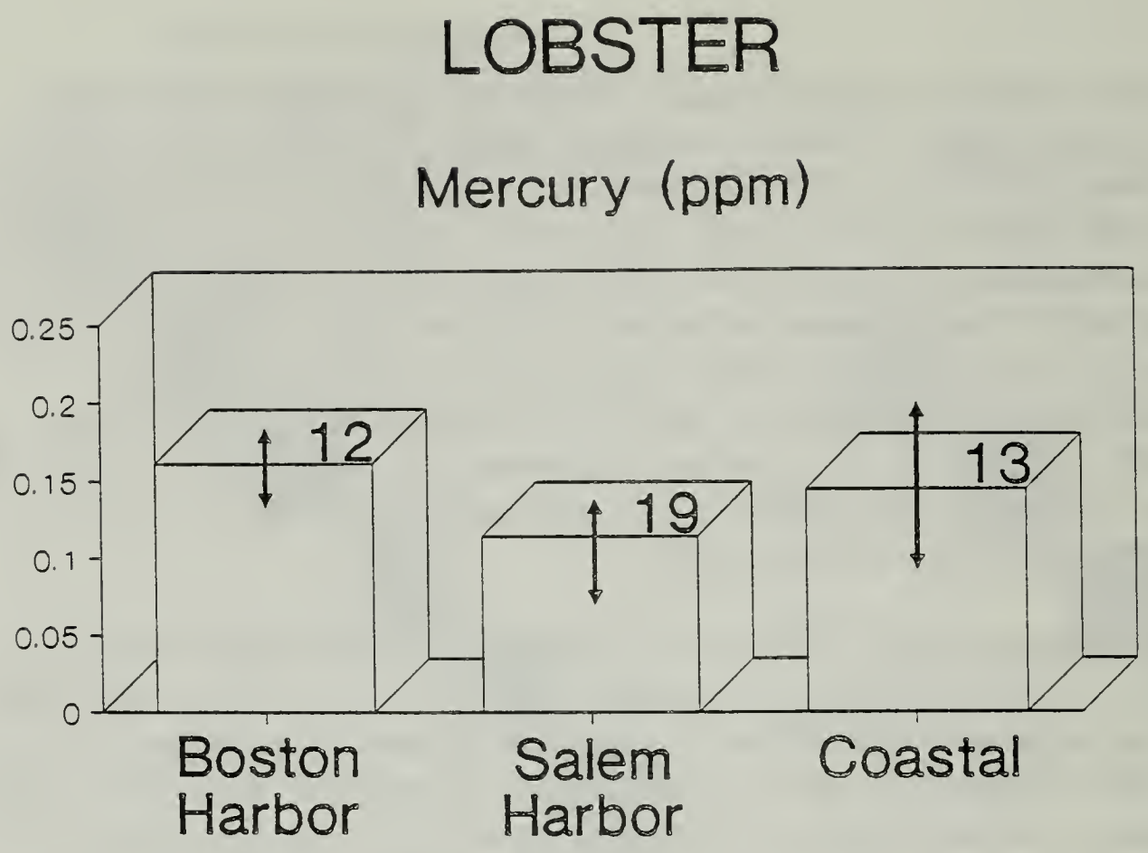


Figure 20. The bars represent the mean mercury levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

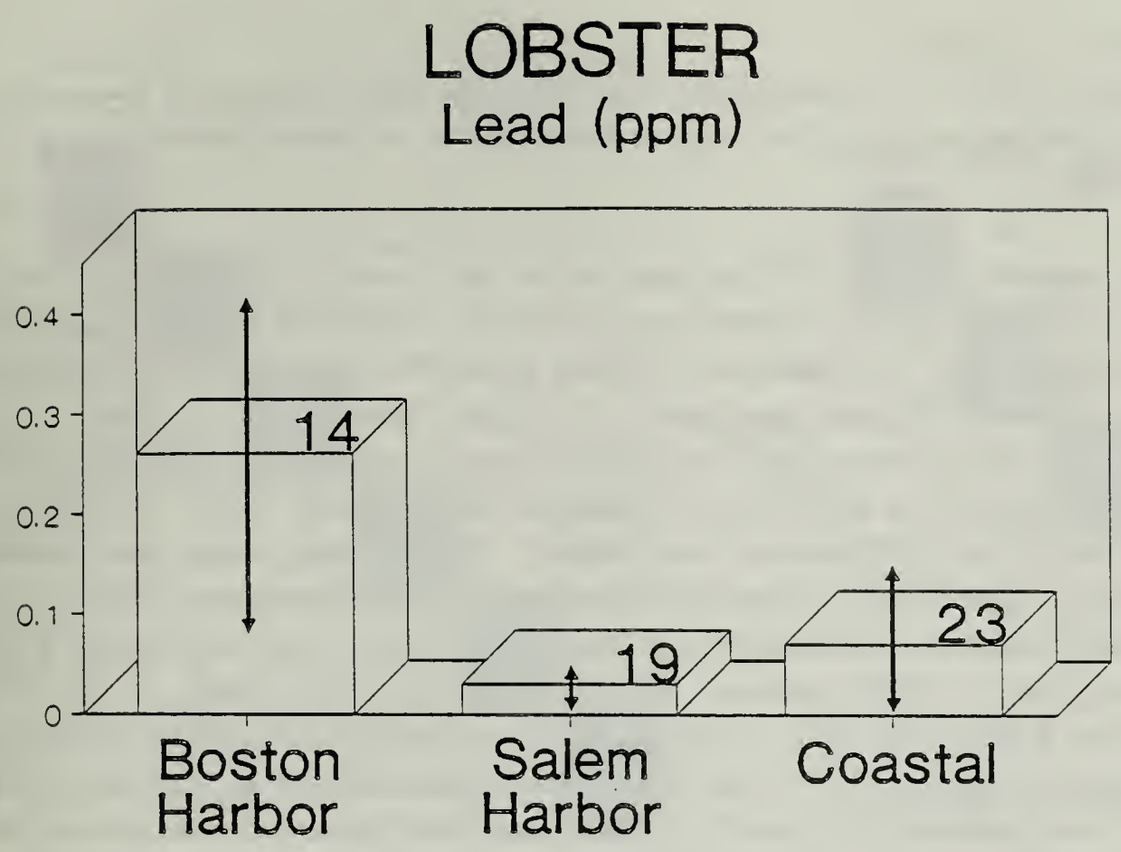


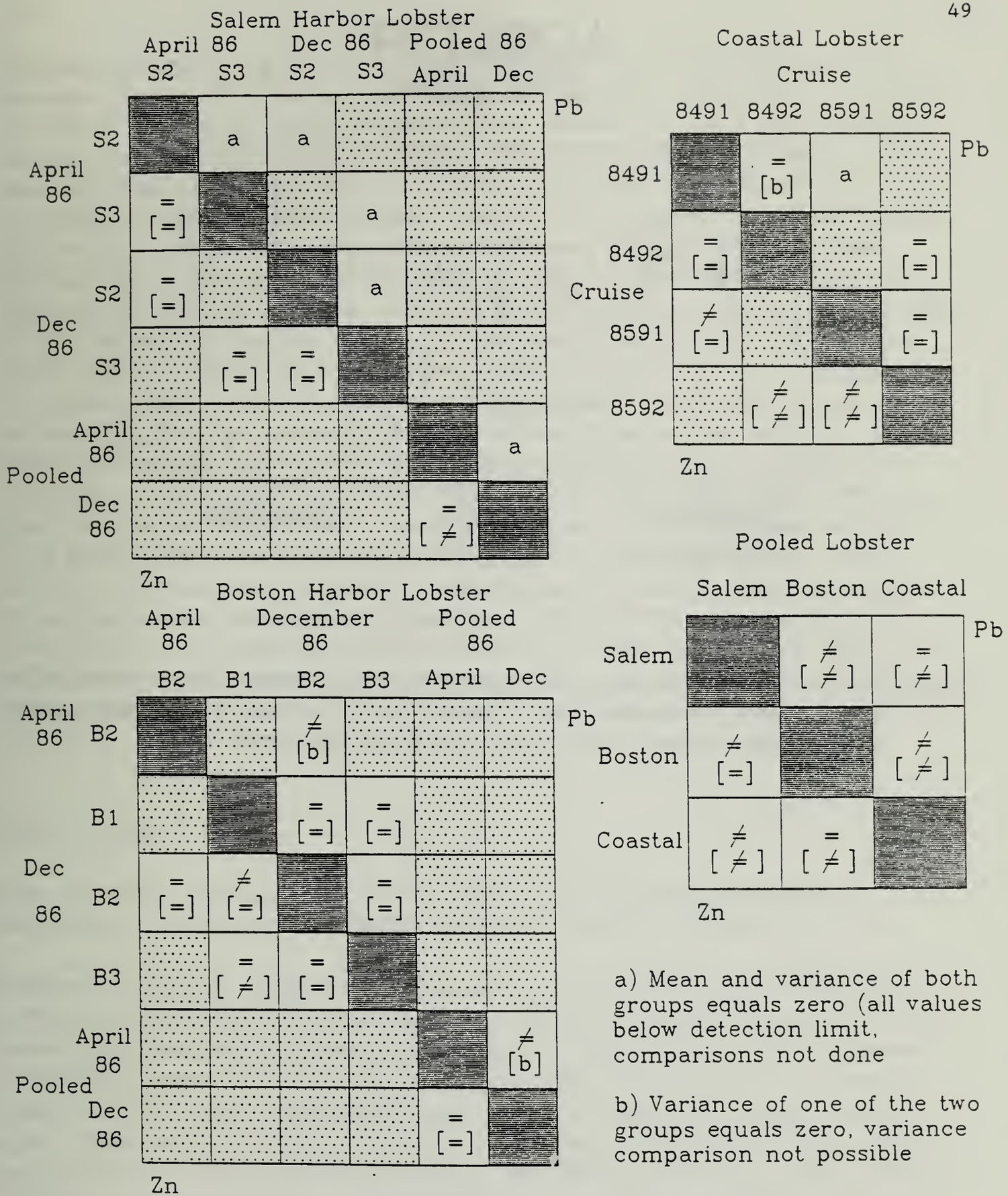
Figure 21. The bars represent the mean lead levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

(Hall et al., 1978). In contrast, lobster muscle tissue from Boston and Salem Harbors contained an average lead concentration of less than 0.1 ppm (Wallace et al., 1988).

The large number of lead data points below the limit of detection (Table C-4, C-5, C-6) affected several ANOVA comparisons. No Salem Harbor comparisons were performed since all lobster samples from 1986 were below the limit of detection (mean: 0.00 ppm, variance: 0.00 ppm) (Table C-4). Lead concentrations in lobster collected from Boston Harbor station B3 were significantly lower in April 1986 compared to December 1986. No other station-to-station differences were found. The pooled April data contained significantly lower lead concentrations than pooled December data (Figure 22). This was not unexpected since the pooled April data consisted solely of station B2 (Table C-5). Lobster obtained from coastal areas in the Spring of 1984 (cruise 8491) and 1985 (cruise 8591) had mean lead levels statistically equal to zero. Therefore, a year-to-year comparison of spring data was not possible. No seasonal or yearly significant differences were found in the coastal lobster samples (Figure 22). Boston Harbor lobster contained lead levels three times higher than coastal lobster and over five times higher than lead levels in Salem Harbor lobster (Table 5). Lobster from coastal areas were not significantly different from Salem Harbor lobster. The variance component of the three pooled groupings were all significantly different (Figure 22). In contrast to lead levels in lobster tissues, the NS&TP sediment survey (NOAA 1988) reported lead concentrations in Boston Harbor (207 ppm dry wt.) and Salem Harbor (260 ppm dry wt.) that were approximately twice as high as the Cape Ann, Massachusetts, station (109 ppm dry wt.).

Zinc: The range of zinc concentrations for all the lobster was 15.4 ppm to 41.4 ppm. The mean zinc concentration for coastal lobster was 28.8 ppm (range: 16.0 ppm to 41.4 ppm). Boston Harbor lobster had more zinc (mean: 28.1 ppm, range: 24.2 ppm to 36.1 ppm) than Salem Harbor lobster (mean: 24.3 ppm, range: 15.4 ppm to 34.8 ppm; Table 5) (Figure 23). In contrast, Wallace et al. (1988) reported that the muscle tissue of Boston Harbor lobster (mean: 17.6 ppm) had less zinc than Salem Harbor lobster muscle (mean: 21.3 ppm). The majority of zinc concentrations in lobster tail and claw meat collected by Hall et al. (1978) were between 20.0 ppm and 30.0 ppm, and the range of zinc levels in lobster from Georges Bank was 10.00 ppm to 183.45 ppm.

Mean zinc levels in Salem Harbor lobster were not spatially or seasonally significantly different. The only significant difference found was between the variances of the pooled April 1986 and pooled December 1986 data sets.



a) Mean and variance of both groups equals zero (all values below detection limit, comparisons not done

b) Variance of one of the two groups equals zero, variance comparison not possible

Figure 22. Summary of statistical analyses of lobster lead and zinc means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Lead comparisons appear to the right of the diagonal, zinc to the left.

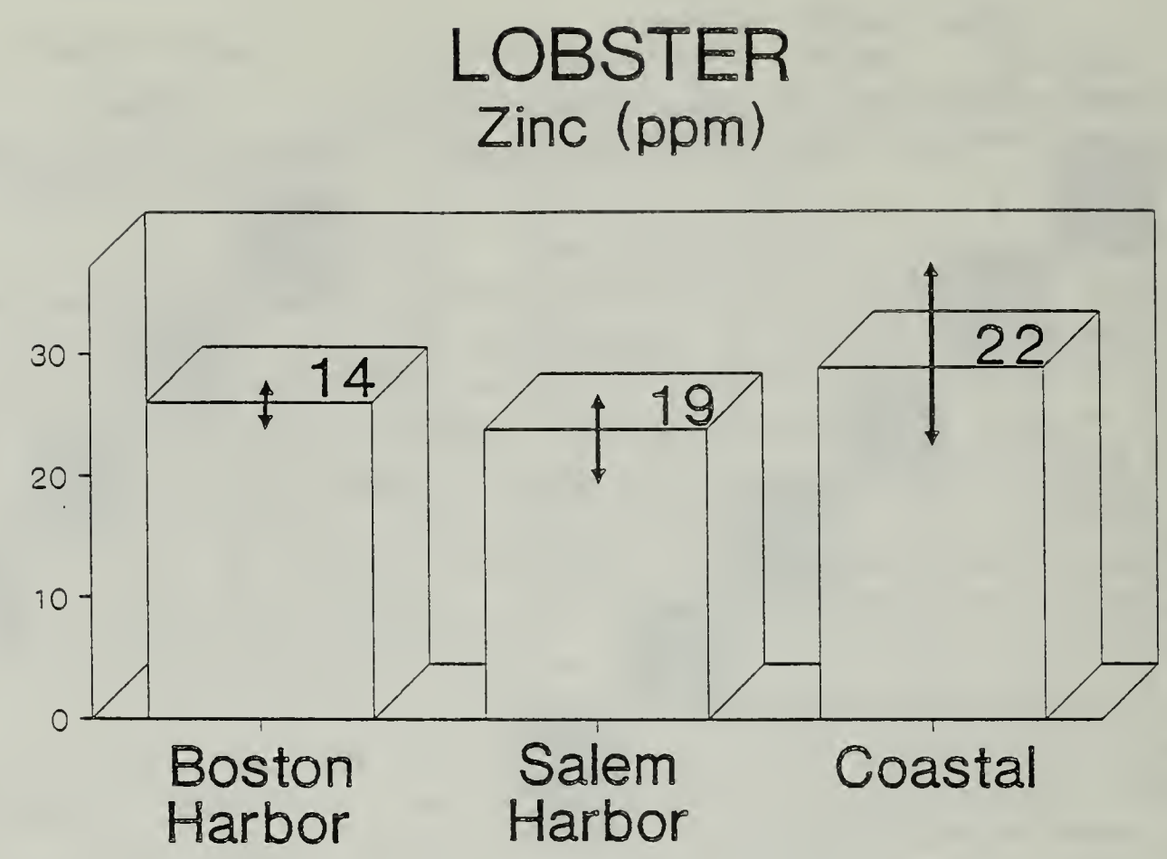


Figure 23. The bars represent the mean zinc levels, in ppm, for lobster. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

Samples collected in April had a larger variance than those obtained in December (Figure 22). Boston Harbor lobster contained significantly more zinc at station B1 than B2 during December 1986. Station B1 had a significantly smaller variance than station B3 during this same period. No other spatial or seasonal significant differences occurred in this data set (Figure 22). Zinc in coastal lobster was more variable than zinc in lobsters from either harbor (Figure 22). There was no significant difference in zinc concentrations between Spring 1984 (cruise 8491) and Fall 1984 (cruise 8492) but lobster caught in Spring 1984 had more zinc than those obtained in Spring 1985 (cruise 8591). Coastal lobster had lower zinc concentrations in Fall 1985 (cruise 8592) than in either Fall 1984 or Spring 1985 (Figure 22). The variance of the coastal lobster pooled data set was significantly different from the variances of the zinc concentrations in lobster from the two harbors. Boston Harbor and coastal lobster mean zinc concentrations were not significantly different but Salem Harbor lobster contained less zinc than lobster from the other two regions (Figure 22). However, Wallace et al.(1988) reported that Salem Harbor lobster were significantly higher in zinc than Boston Harbor lobster. As with lead, low zinc concentrations in lobsters from Salem Harbor did not agree with sedimentary information. NOAA (1988) reported high zinc concentrations in sediments from both Boston (452 ppm dry wt.) and Salem (342 ppm dry wt.) Harbors compared to the concentration at the nearby Cape Ann station (155 ppm dry wt.).

Winter Flounder

Mean trace metal concentrations for winter flounder (*Pseudopluronectes americanus*) from coastal and harbor areas are listed in Table 6.

Cadmium: The range of cadmium concentrations for flounder was 0.000 ppm to 0.088 ppm with coastal flounder tending to have the highest concentrations and Salem Harbor samples the lowest concentrations (Figure 24). Winter flounder from Boston Harbor contained cadmium levels from <0.011 ppm to 0.034 ppm with a mean of 0.012 ppm. Salem Harbor samples had a mean of 0.006 ppm cadmium with a range of <0.011 ppm to 0.020 ppm. Samples obtained from coastal areas had the widest range of concentrations, 0.000 ppm to 0.088 ppm, with a mean of 0.013 ppm cadmium (Table 6). The NS&TP marine environmental quality survey (NOAA, 1987) reported higher cadmium levels in Boston Harbor flounder livers (0.14 ppm dry wt.) than in livers from Salem Harbor flounder (0.08 ppm dry wt.).

Table 6.

Mean concentrations of trace elements (μg/g wet weight)
for winter flounder samples including sample size (parentheses),
standard deviation [brackets], and ranges.

	Cd	Cr	Cu	Hg	Pb	Zn
Salem Harbor	0.006(23)	0.08(23)	0.24(23)	0.045(13)	0.06(23)	4.68(23)
	[0.009]	[0.08]	[0.06]	[0.023]	[0.14]	[0.93]
	<0.011-0.020	<0.01-0.39	0.13-0.36	0.024-0.086	<0.11-0.45	3.41-7.19
Boston Harbor	0.012(35)	0.05(35)	0.29(35)	0.102(23)	0.02(35)	6.57(35)
	[0.010]	[0.03]	[0.22]	[0.049]	[0.07]	[1.60]
	<0.01-0.034	0.00-0.10	0.14-1.49	0.020-0.187	0.00-0.40	4.04-10.2
Coastal Mass.	0.013(21)	0.07(23)	0.31(23)	0.045(14)	0.11(23)	7.02(21)
	[0.020]	[0.06]	[0.12]	[0.024]	[0.17]	[1.96]
	0.000-0.088	0.00-0.24	0.13-0.57	0.016-0.096	0.00-0.59	4.49-11.8

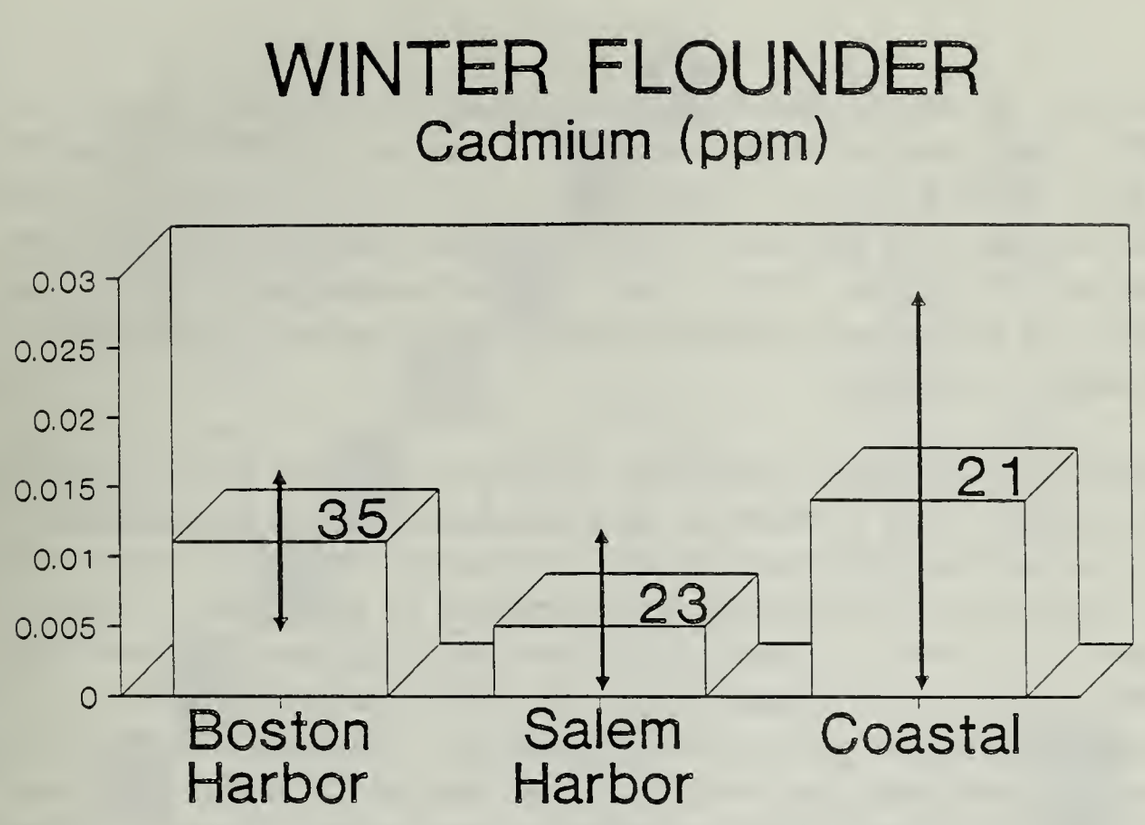


Figure 24. The bars represent the mean cadmium levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

Cadmium levels in Boston Harbor flounder have been reported as low as <0.006 ppm (USEPA, 1988; converted from dry wt. to wet wt.) and as high as 0.03 ppm to 0.15 ppm (Capuzzo et al., 1986). Winter flounder from Long Island Sound contained between 0.02 ppm and 0.06 ppm cadmium (Connecticut Dept. of Environmental Protection, 1987). All flounder collected by Hall et al. (1978) on Georges Bank contained cadmium concentrations below 0.1 ppm, with a range of 0.086 ppm to 0.050 ppm.

One significant difference was found within the cadmium data for Salem Harbor flounder, samples from station S2 were found to contain significantly less cadmium than samples from station S3 in December 1986. No other spatial or seasonal significant differences were detected in Salem Harbor (Figure 25). Boston Harbor flounder at station B2 contained significantly more cadmium in April 1986 compared to December 1986. No other spatial, seasonal, or yearly significant differences were found (Figure 25). Cadmium levels in flounder from coastal areas were more variable than cadmium in harbor flounder. Although the mean cadmium concentration in Spring 1984 (cruise 8491) was not significantly different from Fall of 1984 (cruise 8492), the group variance of the Spring samples was significantly smaller than that of the Fall samples. One significant seasonal and one yearly difference in cadmium concentrations were also found. Cadmium levels were higher in Spring 1985 (cruise 8591) than in Fall 1985 (cruise 8592). Winter flounder obtained in Spring 1984 had lower concentrations than samples from the Spring 1985 (Figure 25). Higher cadmium levels in the Spring 1985 samples may be the result of a spatial rather than seasonal/yearly affect. All of the Spring 1985 flounder were obtained from south of Cape Cod, while samples from both north and south of Cape Cod were included in the other cruises. Possible effects of this sampling pattern in Spring 1985 may also be seen in the ANOVA results for four other metals (Cr, Cu, Hg, and Zn). Pooled Salem Harbor and Boston Harbor flounder had significantly smaller variances than pooled coastal flounder. Boston Harbor and coastal flounder mean cadmium concentrations were not significantly different but Salem Harbor flounder contained significantly less cadmium than flounder from Boston Harbor (Figure 25). In contrast, cadmium levels in lobster from Boston and Salem Harbor were indistinguishable but coastal lobster contained more cadmium than Boston Harbor lobster. The lower cadmium concentrations in Salem Harbor compared to Boston Harbor flounder in this survey correlated with the NS&TP sediment survey (NOAA 1988). NS&TP reported cadmium levels in Salem Harbor sediments (9.79 ppm dry wt.) that were three times higher than those in Boston Harbor sediments (3.24 ppm dry wt.) and nineteen times the level in Cape Ann sediment (0.51 ppm dry wt.).

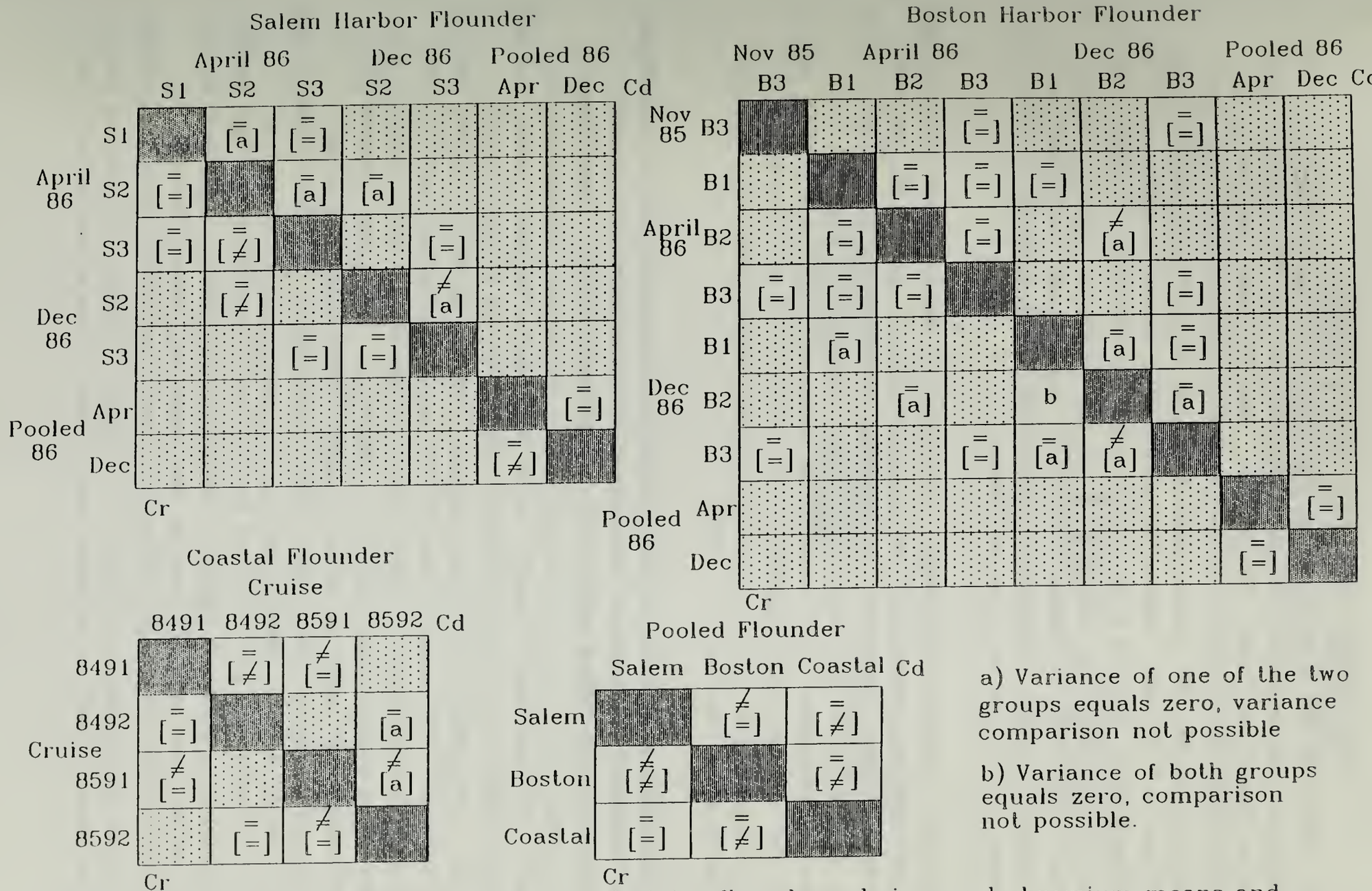


Figure 25. Summary of statistical analyses of winter flounder cadmium and chromium means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Cadmium comparisons appear to the right of the diagonal, chromium to the left.

Chromium: The range of chromium concentrations in winter flounder was 0.00 ppm to 0.39 ppm, Salem Harbor samples tended to have the higher levels and Boston Harbor the lower levels (Figure 26). Most flounder samples in all coastal and harbor areas contained less than 0.15 ppm chromium. The mean chromium concentration for Salem Harbor flounder was 0.08 ppm and the range was <0.01 ppm to 0.39 ppm. Boston Harbor flounder contained a mean of 0.05 ppm chromium with a range of 0.00 ppm to 0.10 ppm (Table 6). Flounder livers from Salem Harbor have been reported to contain 0.74 ppm (dry wt.) while livers from Boston Harbor contained only 0.26 ppm (dry wt.) chromium (NOAA, 1987). Coastal flounder contained a mean chromium concentration of 0.07 ppm with a range of 0.00 ppm to 0.24 ppm (Table 6).

The USEPA (1988) reported that winter flounder from Boston Harbor had 0.00 ppm to 0.34 ppm chromium (converted from dry wt. to wet wt.), with all but one value below 0.05 ppm. Extremely low chromium concentrations (0.00 ppm to 0.08 ppm) have been reported for Long Island Sound (Connecticut Dept. of Environmental Protection, 1987) as well as relatively high levels (0.42 ppm to 0.56 ppm) for the same area (Capuzzo et al., 1986; Reid et al., 1982). Chromium concentrations in winter flounder from Georges Bank varied between 0.1 ppm and 0.3 ppm (Hall et al., 1978).

Mean chromium concentrations in Salem Harbor flounder exhibited no significant spatial or seasonal differences. Station S2 had a significantly larger variance than station S3 in April 1986 than December 1986 and significantly larger variance than station S3 in April 1986. Also, the variance of the pooled April data was significantly larger than pooled December data; this may reflect the effect of the large variance around station S2 data in April (Figure 25). One spatial difference emerged from the ANOVA for Boston Harbor flounder chromium. In December, station B2 samples had significantly lower chromium concentrations than flounder from station B3. No other significant differences were found either spatially, seasonally, or yearly (Figure 25). Coastal flounder were found to contain significantly higher chromium concentrations in Spring 1985 (cruise 8591) than Spring 1984 (cruise 8491) and Fall 1985 (cruise 8592). Whether this is a seasonal/yearly or spatial difference is not possible to discern because all cruise 8591 flounder samples were collected from south of Cape Cod, while winter flounder from both north and south of the cape were included in the other data sets. No other significant seasonal or yearly differences were found in the coastal flounder mean chromium concentrations (Figure 25). Winter flounder from Boston Harbor had a significantly smaller variance than flounder from either Salem Harbor or

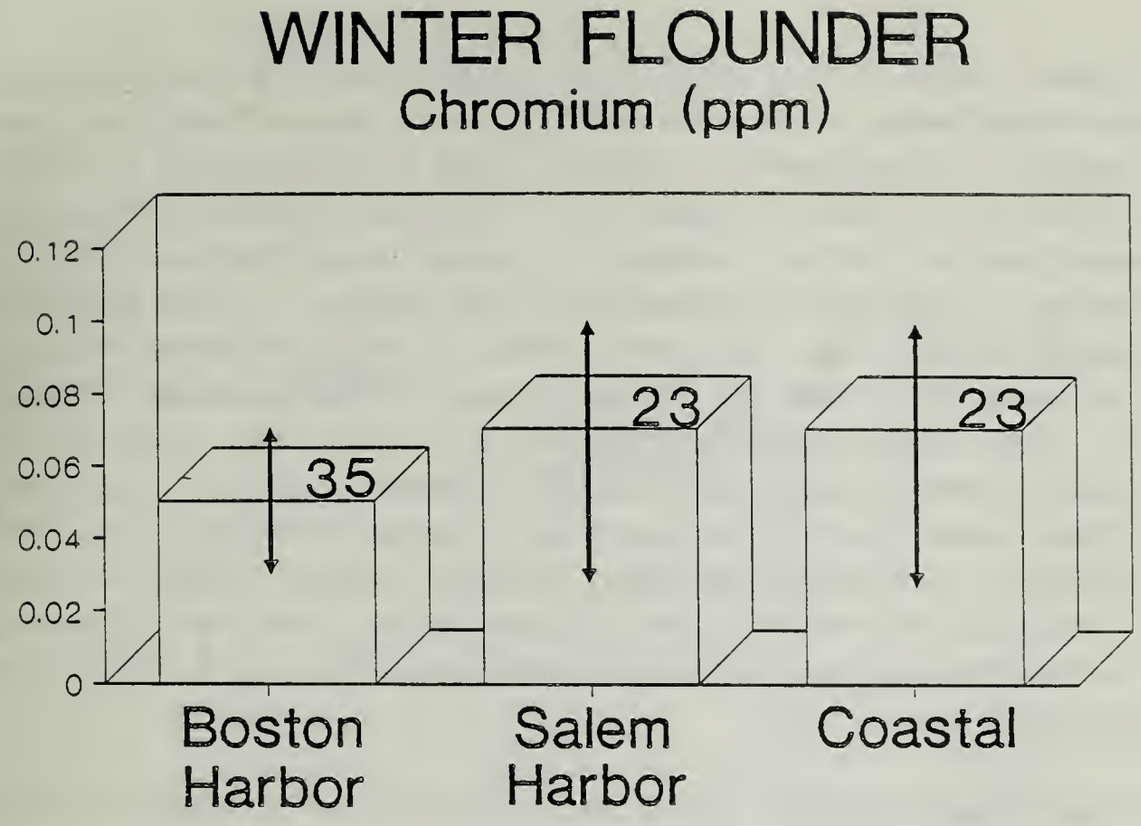


Figure 26. The bars represent the mean chromium levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

coastal areas. Salem Harbor samples had significantly higher concentrations of chromium than Boston Harbor flounder. Mean chromium levels in coastal flounder were not significantly different from concentrations in winter flounder from either harbor (Figure 25). Flounder chromium concentrations in Salem Harbor did not reflect sediment chromium concentrations in Salem Harbor (see chromium in lobsters) as dramatically as lobster. Salem Harbor flounder had approximately the same level of chromium in their tissues as coastal lobster and about 1.5 times the chromium level in Boston Harbor flounder (Table 6). Salem Harbor lobster, however, had about four times the chromium levels found in Boston Harbor and coastal lobster (Table 5). Both lobster and flounder from Boston Harbor were not significantly different from their coastal cohorts, even though the NS&TP sediment survey (NOAA 1988) reported sediment chromium concentrations of 419 ppm dry wt. for Boston Harbor, 100 ppm dry wt. to 200 ppm dry wt. for coastal Massachusetts, and 3,374 ppm dry wt. for Salem Harbor.

Copper: The range of copper concentrations in winter flounder was 0.13 ppm to 1.49 ppm, with coastal samples having the largest mean and Salem Harbor flounder the smallest (Figure 27). The majority of samples had copper concentrations between 0.13 ppm and 0.4 ppm. Flounder in Salem Harbor had a mean copper concentration of 0.24 ppm with a range of 0.13 ppm to 0.36 ppm. Boston Harbor flounder contained a mean of 0.29 ppm copper with a range of below 0.14 ppm to 1.49 ppm. Only one flounder sample collected at station B1, December 1986 exceeded 0.5 ppm (Table 6). The NS&TP marine environmental quality survey (NOAA, 1987) also reported higher copper concentrations in flounder livers from Boston Harbor (15.1 ppm dry wt.) compared to Salem Harbor (10.4 ppm dry wt.). In this study, the mean copper concentration for flounder from coastal Massachusetts was 0.37 ppm, with a range of 0.13 ppm to 0.57 ppm (Table 6).

The USEPA (1988) reported copper levels in Boston Harbor flounder similar to those in this study (0.04 ppm to 0.021 ppm, converted from dry wt. to wet wt.), but Capuzzo et al. (1986) listed flounder copper concentrations in the range of 0.7 ppm to 10 ppm. Values reported for Long Island Sound flounder were similar to our coastal flounder, generally ranging from 0.08 ppm to 0.26 ppm (Reid et al., 1982) with one reported value near the Housatonic River of 3.60 ppm (Connecticut Dept. of Environmental Protection, 1987). Copper concentrations in flounder from Georges Bank varied between 0.2 ppm and 0.4 ppm (Hall et al., 1978).

Salem Harbor flounder at station S2 contained significantly less copper in

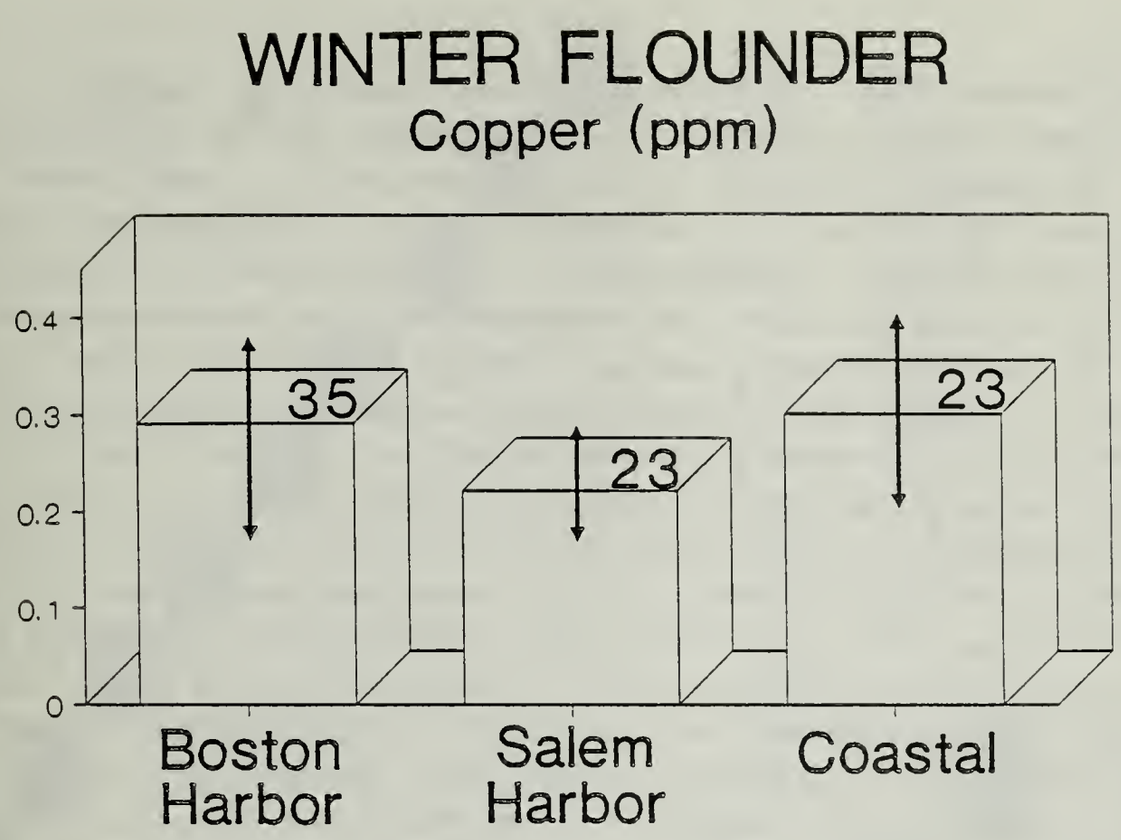
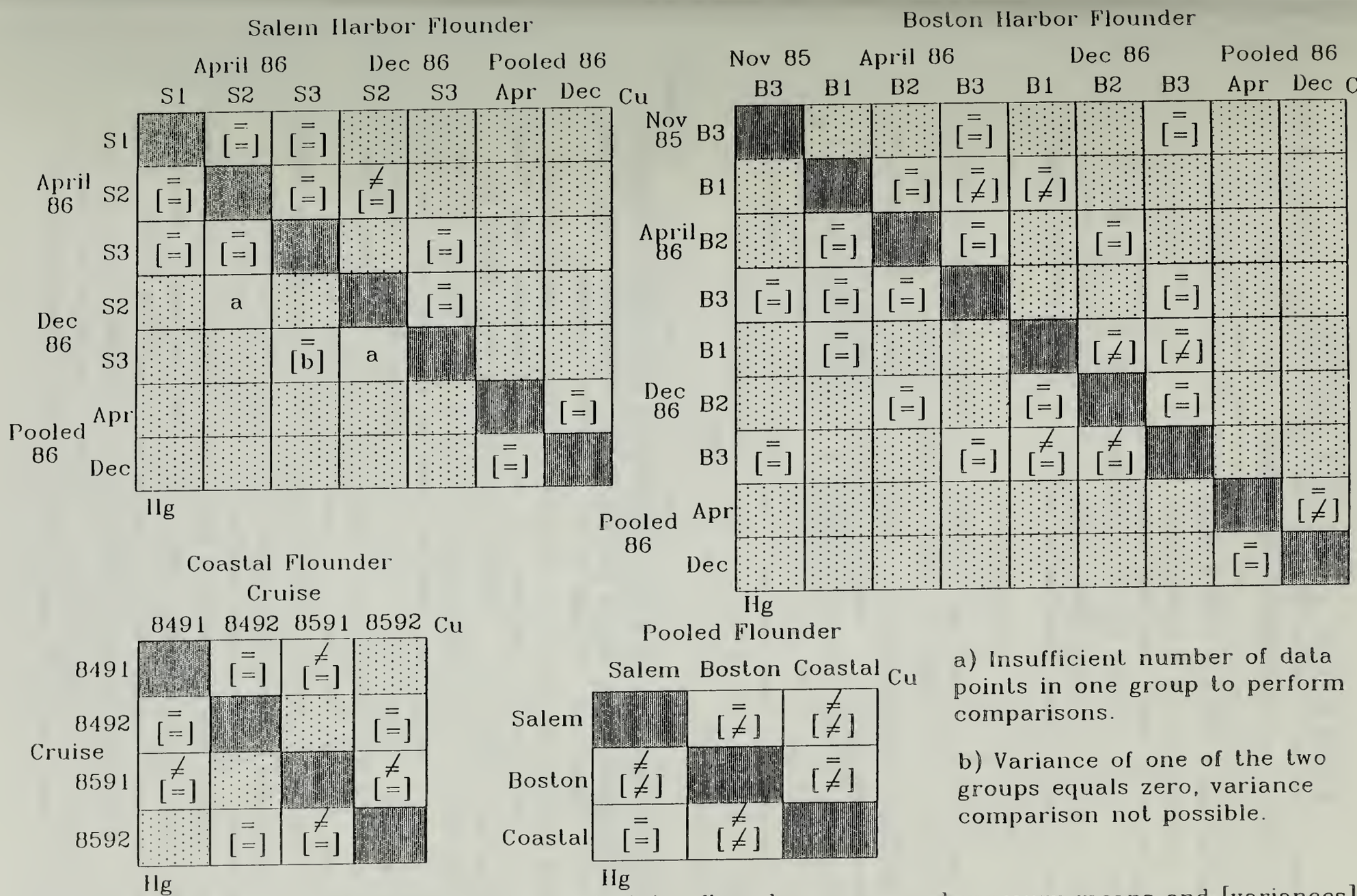


Figure 27. The bars represent the mean copper levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

April than December 1986. No other significant spatial or seasonal differences were found (Figure 28). Although Boston Harbor flounder exhibited no significant spatial, seasonal, or yearly differences in mean copper concentrations, the variance of station B1 samples was significantly different seasonally (April 1986 vs. December 1986), and significantly different from the variance at other stations. The variance of winter flounder copper levels at station B1 was significantly smaller in April than December 1986. In April the variance of station B2 was significantly larger than station B1. For flounder obtained in December 1986, the variance of station B1 was significantly greater than the variance of stations B2 and B3. Pooled April data had a significantly smaller variance than pooled December data (Figure 28). As with cadmium and chromium, copper concentrations in coastal flounder samples from Spring 1985 (cruise 8591) were significantly higher than flounder obtained from Spring 1984 (cruise 8491) or Fall 1985 (cruise 8592). Whether or not these ANOVA differences were the result of true seasonal/yearly biological differences or artifacts of the sampling design were not discernable in this study. However, we note that several distinct populations of winter flounder have been previously described by Pierce and Howe (1977), and all of the flounder samples in Spring 1985 were collected from south of Cape Cod. No other seasonal or yearly differences among coastal flounder were detected by ANOVA (Figure 28).

Winter flounder from all three regions (Boston Harbor, Salem Harbor, and coastal Massachusetts) had significantly different variances in their pooled copper data. Salem Harbor samples had a significantly smaller variance than samples from the other areas while flounder from Boston Harbor were found to have a significantly larger variance than flounder from coastal sites. Coastal flounder contained significantly more copper than flounder from Salem Harbor (Figure 28). As with other metals, regional differences in flounder copper data were different than the lobster data. While Salem Harbor flounder had significantly lower copper concentrations than coastal flounder, copper levels in lobster from Salem Harbor were significantly lower than lobster from coastal areas as well as Boston Harbor. Like the lobster data, copper concentrations in winter flounder did not entirely reflect copper levels in the sediment. The NS&TP sediment survey (NOAA, 1988) found lowest copper levels in coastal Cape Ann sediment (33.38 ppm dry wt.) with higher concentrations in Salem Harbor (125.67 ppm dry wt.) and Boston Harbor (256.13 ppm dry wt.). Coastal flounder would therefore be expected to have the lowest copper concentrations and Boston Harbor samples the highest, however this pattern was not reflected in our data (Table 6).



a) Insufficient number of data points in one group to perform comparisons.

b) Variance of one of the two groups equals zero, variance comparison not possible.

Figure 28. Summary of statistical analyses of winter flounder copper and mercury means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by $\neq$ ($p<0.05$). Copper comparisons appear to the right of the diagonal, mercury to the left.

Mercury: The range of winter flounder mercury concentrations was 0.016 ppm to 0.187 ppm, Boston Harbor samples tended to have higher concentrations than flounder from other areas (Figure 29). The mean mercury concentration in Salem Harbor flounder was 0.045 ppm with a range of 0.024 ppm to 0.086 ppm. The mean mercury concentration in Boston Harbor flounder was 0.102 ppm with a range of 0.020 ppm to 0.187 ppm. The mean mercury level in coastal flounder was 0.045 ppm with a range of 0.016 ppm to 0.096 ppm (Table 6). The NS&TP marine environmental quality survey (NOAA, 1987) also listed higher mercury concentrations in flounder livers from Boston Harbor (0.12 ppm dry wt.) than Salem Harbor (0.09 ppm dry wt.).

Mercury levels similar to concentrations detected in the present study have been listed in Capuzzo et al. (1986) for Boston Harbor flounder (0.04 ppm to 0.5 ppm) while the USEPA (1988) reported slightly lower values (0.006 ppm to 0.086 ppm, converted from dry wt. to wet wt.). Mercury levels in winter flounder from Georges Bank were generally below 0.1 ppm, but individuals varied between 0.000 ppm and 0.540 ppm (Hall et al., 1978). Mercury levels in winter flounder from coastal Massachusetts were similar to levels reported in Long Island Sound (0.01 ppm to 0.12 ppm) by the Connecticut Dept. of Environmental Protection (1987) and Reid et al. (1982).

No significant ANOVA differences were found within the Salem Harbor flounder mercury data. Comparisons were limited by the lack of replicates at station S2 in December 1986 (Figure 28). Boston Harbor flounder contained significantly less mercury at station B3 than at stations B1 and B2 during December 1986. No other spatial, seasonal, or yearly differences were found in the Boston data set (Figure 28). Coastal flounder obtained during the Spring 1985 (cruise 8591), were significantly different from winter flounder sampled at other times. Spring 1985 samples contained more mercury than those from either Spring 1984 (cruise 8491) or Fall 1985 (cruise 8592). No other seasonal or yearly ANOVA differences were found (Figure 28). As with other previously mentioned metals, this may be a sampling artifact, a true seasonal/yearly difference, or both. ANOVA comparisons of pooled data showed no significant difference between mean Salem Harbor and coastal flounder mercury concentrations. Boston Harbor samples had a significantly larger variance and mean mercury level than Salem Harbor and coastal flounder (Figure 28). The NS&TP sediment survey (NOAA, 1988) found that sediment in Boston Harbor contained the same level of mercury as sediment in Salem Harbor (1.7 ppm dry wt.) but a much lower mercury concentration in sediment from nearby Cape Ann, Massachusetts (0.25 ppm dry wt.). Coastal flounder would therefore be expected to have lower levels of mercury than flounder from both harbors;

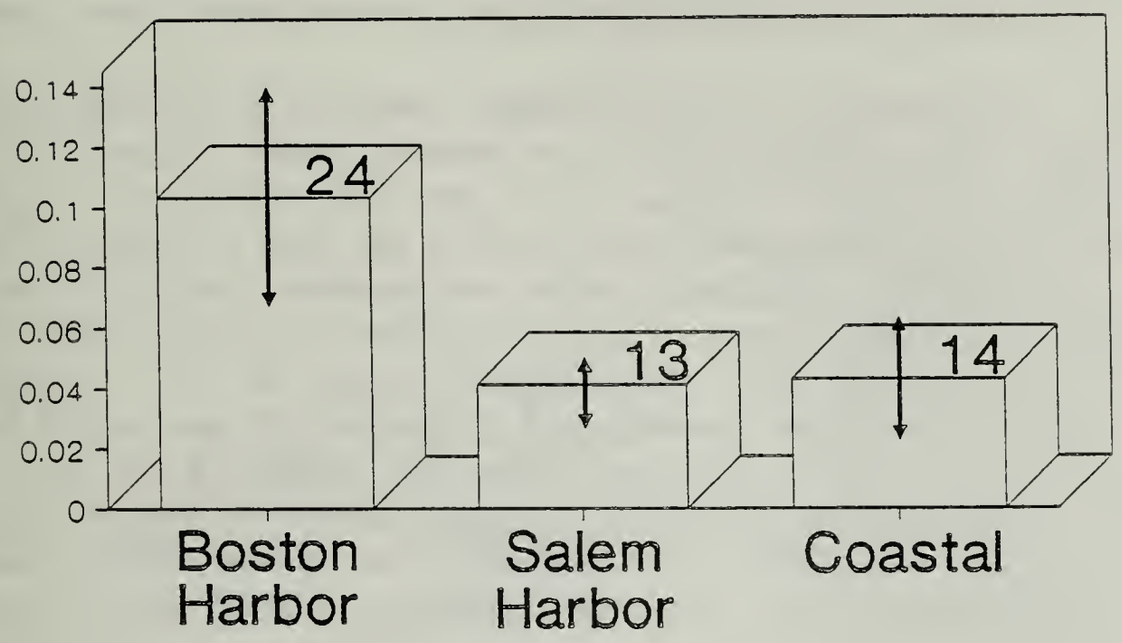


Figure 29. The bars represent the mean mercury levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

this was not the case (Table 6). Our lobster data also contained more mercury in Boston Harbor than Salem Harbor, but unlike winter flounder, Boston Harbor lobster did not have significantly more mercury than coastal samples.

Lead: Lead concentrations in winter flounder ranged from 0.00 ppm to 0.59 ppm, the higher levels tended to be in the coastal sample (Figure 30). Salem Harbor flounder contained <0.11 ppm to 0.45 ppm lead with a mean of 0.06 ppm lead. Boston Harbor samples had a mean of 0.02 ppm with a range of 0.00 to 0.40 ppm lead (Table 6). The NS&TP marine environmental quality survey (NOAA, 1987) found that flounder livers from Boston Harbor contained higher lead levels (0.63 ppm dry wt.) than Salem Harbor (0.53 ppm dry wt.). Coastal flounder lead concentrations ranged from 0.00 ppm to 0.59 ppm with a mean of 0.11 ppm (Table 6). Mean lead concentrations may be affected by the variability of the limit of detection and large numbers of samples below the limit of detection. The USEPA (1988) reported that Boston Harbor flounder contained lead concentrations <0.04 ppm (converted from dry wt. to wet wt.), and Capuzzo et al. (1986) listed the range of lead concentrations in Boston Harbor flounder as 0.07 ppm to 0.65 ppm. In Long Island Sound Reid et al. (1982) reported lead concentrations in flounder as <0.06 ppm, and the Connecticut Dept. of Environmental Protection (1987) reported a range of lead concentrations between 0.16 ppm to 0.44 ppm. Winter flounder collected by Hall et al. (1978) on Georges Bank contained mean lead concentrations between 0.3 ppm and 0.4 ppm, however some samples exceeded 0.6 ppm.

Statistical analyses of Salem Harbor data revealed no significant spatial or seasonal differences (Figure 31). We believe this is the result of the large proportion of samples from each station with concentrations below the detection limits. For example, four of the five samples collected at station S1 and five of the six samples from station S3 in April had values below the limits of detection (Table C-7). Since values below the detection limits were set to zero for the ANOVA, stations such as these would all have mean lead concentrations close to zero. Statistical comparisons of Boston Harbor samples were also affected by the detection limits. At many sites all of the specimens collected had concentrations below the detection limit, for these sites both the mean and variance would be zero. Comparisons of two such sites were not performed, and comparisons which included one site with a zero variance were not statistically possible. For those comparisons which could be accomplished, Boston Harbor station B3 was found to have a significantly larger variance than station B2 in April 1986 but no significant differences were found between station mean concentrations (Figure 31). As with Salem Harbor samples, the nonsignificant differences between mean lead values may

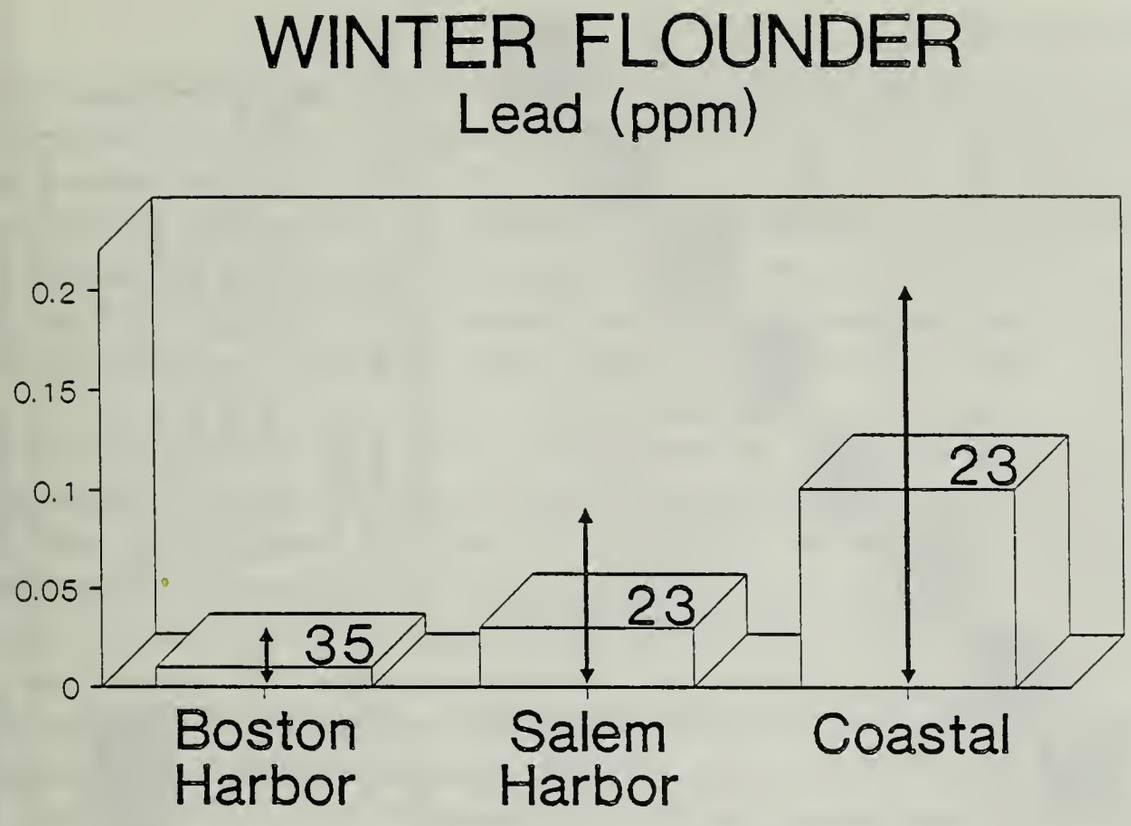
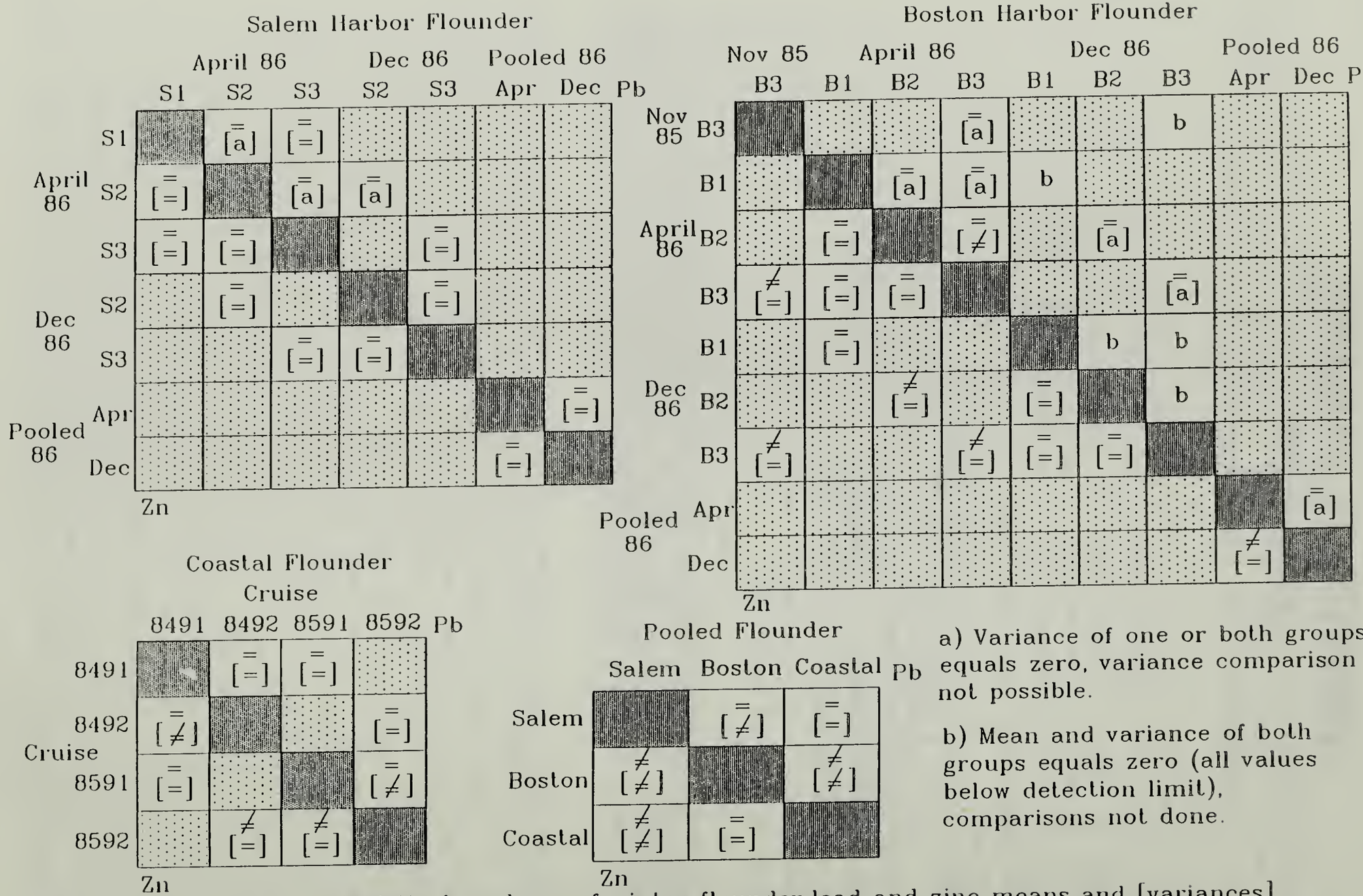


Figure 30. The bars represent the mean lead levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.



a) Variance of one or both groups equals zero, variance comparison not possible.

b) Mean and variance of both groups equals zero (all values below detection limit), comparisons not done.

Figure 31. Summary of statistical analyses of winter flounder lead and zinc means and [variances]. Comparisons which were not statistically different are signified by =, statistically different comparisons by ≠ ($p<0.05$). Lead comparisons appear to the right of the diagonal, zinc to the left.

have been an artifact of the affects of large proportions of concentrations below the detection limits at these sites (Table C-8, Appendix C). Coastal flounder samples were less affected than harbor samples by values below detection limits, therefore the ANOVA was conducted for lead. No seasonal or yearly significant differences were found in the mean lead levels but samples from Spring 1985 (cruise 8591), were found to have a significantly larger variance than samples from Fall 1985 (cruise 8592) (Figure 31).

Analysis of the three pooled winter flounder mean lead concentrations showed that lead concentrations in Boston Harbor flounder had a significantly lower variance than Salem Harbor and coastal flounder. Salem Harbor flounder mean lead concentrations were not significantly different from either Boston Harbor or coastal flounder while samples obtained from Boston Harbor were significantly lower in lead than samples from coastal areas (Figure 31). This distribution was very different from that found for lobster in which Boston Harbor lobster were significantly higher in lead than either Salem Harbor or coastal lobster (Table 5). Finding high lead levels in coastal flounder compared to Boston Harbor samples again contrasted with sedimentary data. The NS&TP sediment survey (NOAA, 1988) found higher concentrations of lead in sediment from Salem Harbor (260 ppm dry wt.) and Boston Harbor (207 ppm dry wt.) than at Cape Ann, Massachusetts (109 ppm dry wt.).

Zinc: The range of zinc concentrations in winter flounder was 3.41 ppm to 11.8 ppm. Salem Harbor flounder had lower levels than flounder from other sites (Figure 32). The mean zinc concentration in Salem Harbor flounder was 4.68 ppm with a range of 3.41 ppm to 7.19 ppm. Boston Harbor flounder contained a mean zinc concentration of 6.57 ppm with a range of 4.04 ppm to 10.2 ppm (Table 6). Zinc concentrations have also been found to be higher in Boston Harbor flounder liver (86 ppm dry wt.) than Salem Harbor flounder liver (82 ppm dry wt.) (NOAA, 1987). Coastal flounder contained a mean of 7.02 ppm zinc with a range of 4.49 ppm to 11.76 ppm (Table 6). This was the highest observed mean and largest range of zinc concentrations among flounder from all areas (Figure 32). Reid et al. (1982) reported zinc levels in winter flounder from Long Island Sound between 2.94 ppm and 4.96 ppm. The Connecticut Dept. of Environmental Protection (1987) found a wide range of zinc concentrations (3.9 ppm to 19.0 ppm) in Long Island Sound flounder, however, only one sample set exceeded 6.93 ppm. Hall et al. (1978) reported that winter flounder from Georges Bank usually contained zinc concentrations between 4.0 ppm to 6.0 ppm, but zinc levels could be as low as 1.63 ppm or as high as 12.50 ppm.

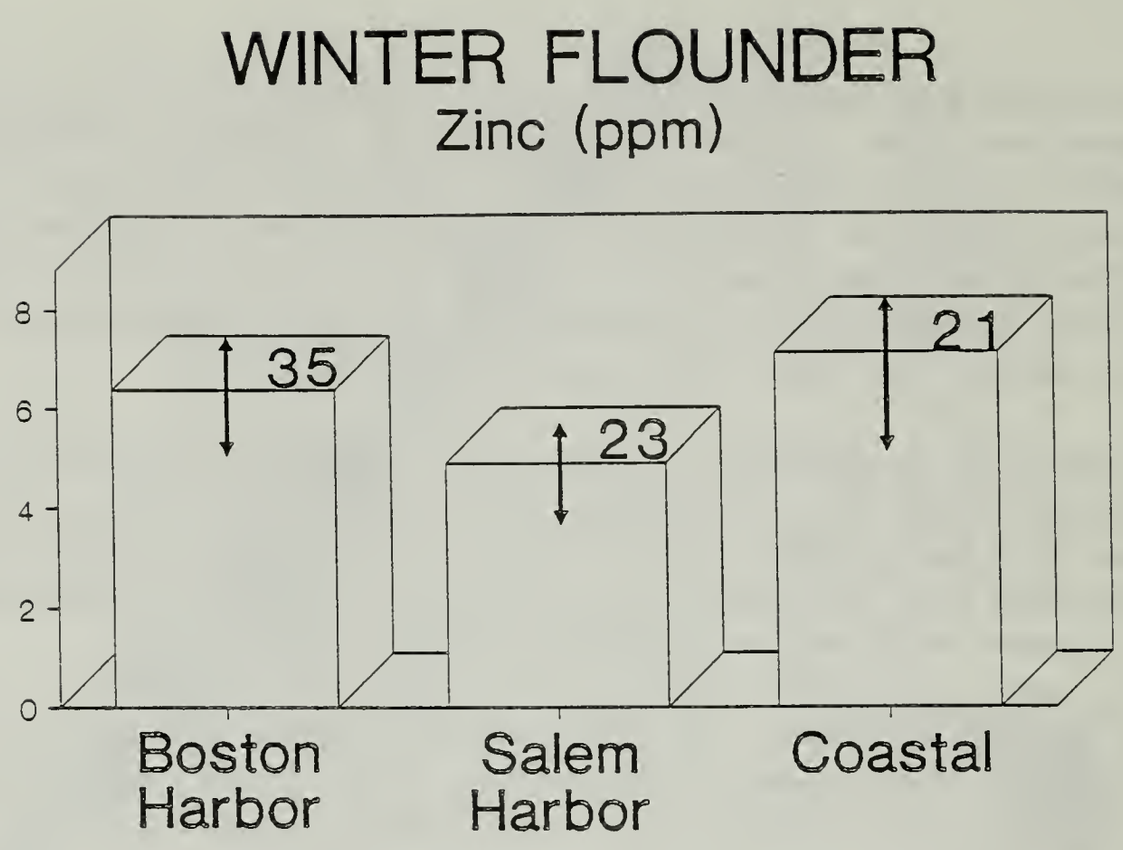


Figure 32. The bars represent the mean zinc levels, in ppm, for winter flounder. The double headed arrow shows the standard deviation around each mean. The number above the bar is the sample size for each mean.

Data comparisons among Salem Harbor flounder revealed no significant spatial or seasonal differences (Figure 31). Flounder from Boston Harbor exhibited both seasonal and yearly significant differences in zinc concentrations but no significant spatial variability. Station B3 samples contained significantly more zinc in November 1985 than December 1986 but significantly less in November 1985 than April 1986. Flounder at station B2 and station B3 had significantly higher concentrations in April than December 1986. The pooled April, 1986, winter flounder data (Figure 31) were also significantly higher in zinc than pooled December 1986 samples. Coastal flounder samples contained more zinc in Fall 1984 (cruise 8492) and Spring 1985 (cruise 8591), compared to Fall 1985 (cruise 8592). Winter flounder obtained during the Spring 1984 (cruise 8491) had a significantly larger variance than flounder caught in the Fall 1984 (cruise 8492) (Figure 31).

Pooled Salem Harbor flounder contained significantly less zinc and a smaller variance than flounder from either Boston Harbor or coastal areas. Boston Harbor and coastal samples were not significantly different (Figure 31). This parallels the lobster data (Table 5). The relatively high zinc values in coastal flounder were contrary to expected levels based upon sediment data. The NS&TP sediment survey (NOAA 1988) reported that sediment near Cape Ann, Massachusetts, contained only 155 ppm (dry wt.) zinc compared to 342 ppm (dry wt.) for Salem Harbor and 452 ppm (dry wt.) for Boston Harbor.

CONCLUSIONS AND RECOMMENDATIONS

Our analyses of trace metals (Cd, Cr, Cu, Hg, Pb, Zn) in six marine species contributes needed baseline information for two polluted urban harbors (Boston and Salem) and a wide geographic area of coastal Massachusetts. The range of metal concentrations in our data were similar to levels previously reported for the same species. Metal concentrations comparable to levels we detected in harbor samples have been previously reported from other areas of coastal Massachusetts and habitats far removed from urban input. For example, the range of mercury levels in Boston Harbor winter flounder was 0.020 ppm to 0.187 ppm and although these levels were statistically higher than other areas in this study, Hall et al. (1978) reported a range of mercury concentrations in Georges Bank winter flounder of 0.100 ppm to 0.280 ppm. With relatively high mercury levels reported for winter flounder far removed from land, it cannot be definitively concluded that mercury levels in Boston Harbor flounder are elevated above mercury levels in coastal flounder due to urban inputs. To detect such a regional difference would require extremely large sample sizes. Cossa (1988) reported such a study. A large number of samples consisting of mussels from 591 stations in Europe, North America, and Asia was necessary to reveal a correlation between cadmium concentrations in seawater and mussels on a global scale. Several problems may also arise when trying to compare metals data from different reports. These problems include lack of interlaboratory calibration, different methodologies, lack of standard reference materials, nonstandard reporting of quality control, and a lack of biological information needed to interpret differences in metal concentrations among various species and tissue types (Capuzzo et al. 1986).

While bivalve molluscs are appropriate sentinel organisms for monitoring contaminants within an environment, e.g. an urban harbor, they do not lend themselves well to monitoring contaminants between harbor and coastal deep water areas, since no bivalve mollusc is found ubiquitously in both nearshore and offshore environs. The blue mussel, which has been successfully used for the NS&TP Mussel Watch Program (NOAA, 1989) is generally restricted to shallow depths (Gosner, 1978) although they are occasionally taken by otter trawl in deeper waters of coastal Massachusetts (A. Howe, personal communication). Interspecies differences in metal uptake, therefore, precluded harbor versus coastal comparisons for the purpose of discerning increased tissue levels from urban inputs. Anthropogenic influences, for example, cannot be deduced when comparing softshell clam with 0.78 ppm chromium from Salem Harbor, an area known to contain extremely high chromium levels in sediment, to ocean quahog

from coastal (less impacted) areas with 0.66 ppm chromium. Interspecies differences in metals concentrations of more than two orders of magnitude can be found in this study. For example, lead in the three coastal species, that is, from the same environment, is as low as 0.07 ppm in surf clam and as high as 1.70 ppm in ocean quahog and 1.76 ppm in blue mussel. We conclude that all variance inequalities found in statistical analyses of our bivalve species could be attributed to interspecies differences.

The lobster and flounder metal data ANOVA comparisons also revealed unequal variances between geographic areas, for example, Boston and Salem Harbor lobster had similar mean cadmium concentrations but had different variances. These differences are not the result of interspecies effects but indicate that factors besides the availability of metals in sediment are influencing tissue concentrations. These factors could not be readily determined. They may include differences in physical/chemical parameters such as temperature and salinity; sediment composition; biological parameters such as the organism's age, size, physiological condition, reproductive stage, and molt cycle; and synergistic or antagonistic effects of other pollutants on the bioavailability and uptake of metals (Cain and Luoma, 1986; Eisler, 1985, 1986; Engel and Brouwer, 1984; Engel and Brouwer, 1987; Heil, 1986; Langston, 1986; Patel et al., 1985; Steimle et al., 1986; Wallace et al., 1988). These factors may lead to specimens collected from one region, e.g. Boston Harbor, appearing to behave as a different population than samples obtained from another area, e.g. Salem Harbor. Differences in tissues analyzed and organism physiology must also be recognized when interpreting multispecies studies such as this. For example, lobster samples generally contained higher absolute amounts of metals than flounder (Tables 5 and 6), but lobster samples contained the tomalley (hepatopancreas) and muscle tissue whereas flounder samples contained only muscle tissue. Additionally, since copper is a major constituent of lobster blood (hemocyanin) higher copper concentrations in lobster compared to some other species is to be expected.

In many instances the levels of metals found in tissues of marine species did not reflect the relative sedimentary metal concentrations. For example, Salem Harbor sediments contained three times the amount of cadmium found in Boston Harbor and nineteen times more than in a coastal (Cape Ann) sample (NOAA, 1988). This pattern was not reflected in lobster and flounder tissues. Coastal lobster contained approximately twice the cadmium found in Boston Harbor and Salem Harbor lobster, while cadmium levels in Salem Harbor flounder were one-half those found in both Boston Harbor and coastal flounder. When simultaneously examining concentrations of all six metals we noted that

coastal samples generally contained metals levels similar to or higher than levels found in samples from harbor areas, with the exception of one or two extremely high values in each of the harbor data sets. Mean metal concentrations were higher in the coastal lobster except for mercury and lead in Boston Harbor and chromium in Salem Harbor samples (Table 5). All mean metal concentrations for harbor flounder were lower than coastal flounder except mercury in Boston Harbor and chromium (marginally) in Salem Harbor (Table 6). These are further indications that both environmental and physiological factors, such as those listed above, may affect tissue metal concentrations and need to be more fully understood.

Our study provides information on tissue concentrations of metals for a variety of benthic marine species over a large area of Coastal Massachusetts and two urban harbors. Unlike previous reports which studied organisms from a particular area and/or relied on multiple sources for laboratory analyses the information provided in this report was collected over most of the territorial waters of the Commonwealth using a common analytical method for all samples. Still, we recognize that more work is needed in order to monitor long-term ecological trends in metal accumulation by benthic organisms both seasonally and spatially, as well as to monitor potential exposure for human populations. To do this we recommend the following modifications for future monitoring surveys:

1. The continued use of edible tissues for assessing metal exposure for human populations is recommended. However, ecological comparisons of metal uptake and accumulation among multiple species should be based on similar tissue(s). Comparisons of flounder muscle tissue, for example, should be made with lobster muscle tissue. Similarly, comparisons of flounder liver with lobster tomalley (hepatopancreas) are recommended. Comparisons of mixed tissues between species should be avoided since different tissues have the capacity to accumulate different metal concentrations.

2. Comprehensive sampling of sediment and the species in this report for one or two years is recommended to better monitor trace metals in the environment that are available for uptake by benthic marine species. Sites could then be selected for long-term monitoring.

3. The use of sedentary bivalve species for monitoring trace metals is recommended provided that a common species can be monitored both in the

urban harbors and coastal areas. Interspecies comparisons of metal concentrations in bivalves should be avoided. The blue mussel may prove acceptable since it can survive in coastal areas and harbors and is currently used by the Mussel Watch Program. A possible monitoring strategy would be to establish a reference site, or sites, in coastal areas removed from Boston and Salem Harbor where a common species can be obtained at an artificial mooring.

4. Continue sampling for lobster and flounder since both species are good indicators of metal uptake for exposure assessment (USEPA, 1989). Regional population differences such as those reported by Pierce and Howe (1977) for winter flounder should also be studied to better understand the biological variability associated with metal uptake by marine organisms.

LITERATURE CITED

Breteler, R.J. (ed.), 1984. Chemical pollution of the Hudson-Raritan Estuary. NOAA Technical Memorandum NOS OMA 7. 72 pp.

Cain, D.J., and S.N. Luoma, 1986. Effect of seasonally changing tissue weight on the trace metal concentrations in the bivalve *Macoma balthica* in San Francisco Bay. Marine Ecology Progress Series. 28:209-217.

Capuzzo, J.M., A. McElroy, and G.T. Wallace, 1986. Fish and shellfish in New England waters: An evaluation and review of available data on the distribution of chemical contaminants. prepared for Coast Alliance, Washington D.C. 59 pp.

Connecticut Department of Environmental Protection, 1987. Report on Long Island Sound Activities. 162 pp.

Cossa, D., 1988. Cadmium in *Mytilus spp.*: worldwide survey and relationship between seawater and mussel content. Marine Environmental Research. 26:265-284.

DiGuilio, R., and P. Scanlon, 1985. Heavy metals in aquatic plants, clams, and sediments from the Chesapeake Bay, U.S.A. Implications for waterfowl. The Science of the Total Environment. 41:259-274.

Eisler, R., 1985. Selenium hazard to fish, wildlife, and invertebrates: a synoptic review. U.S. Dept. of the Interior, Fish and Wildlife Service. Biological Report 85(1.5). 57 pp.

Eisler, R., 1986. Chromium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Dept. of the Interior, Fish and Wildlife Service. Biological Report 85(1.6). 60 pp.

Engel, D.W., and M. Brouwer, 1984. Trace metal-binding proteins in marine molluscs and crustaceans. Marine Environmental Research. 13:177-194.

Engel, D.W., 1987. Metal regulation and molting in the blue crab, *Callinectes sapidus*: copper, zinc, and metallothionein. Biological Bulletin. 172:69-82.

Engel, D.W., and M. Brouwer, 1987. Metal regulation and molting in the blue crab, *Callinectes sapidus*: metallothionein function in metal metabolism. Biological Bulletin. 173:239-251.

Gosner, K.L., 1978. A Field Guide to the Atlantic Seashore. Houghton Mifflin Co., Boston. 327 pp.

Greig, R.A., and G. Sennefelder, 1985. Metals and PCB concentrations in mussels from Long Island Sound. Bulletin of Environmental Contamination and Toxicology. 35:331-334.

Hall, R.A., E.G. Zook, and G.M. Meaburn, 1978. National Marine Fisheries Service survey of trace elements in the fishery resource. NOAA Technical Report NMFS/SSRF-721. 313 pp.

Hatch, W.R., and W.L. Ott, 1986. Determination of sub-microgram quantities of mercury by atomic absorption spectrophotometry. Analytical Chemistry. 40(14):2085-2087.

Heil, D., 1986. Evaluation of trace metal monitoring in Florida shellfish. Division of Marine Resources, Tallahassee, Florida. 186 pp.

Keith, L.H., W. Crummett, J. Deegan, Jr., R.A. Libby, J.K. Taylor, and G. Wentler, 1983. Principles of environmental analysis. Analytical Chemistry. 55(14):2210-2218.

Langston, W.J., 1986. Metals in sediments and benthic organisms in the Mersey Estuary. Estuarine and Coastal Shelf Science. 23:239-261.

Mass. Division of Marine Fisheries, 1985. Assessment at Mid-Decade: economic, environmental, and management problems facing Massachusetts' commercial and recreational marine fisheries. Publ. #14224-65-500-10-85-C.R. 31 pp. w/figures and tables.

New England Aquarium, 1988. New England Aquarium Mussel Watch: 1987 and 1988 data. 7pp.

NOAA, 1984. National Status and Trends Program. Progress report and preliminary assessment of findings of the benthic surveillance program - 1984. National Oceanic and Atmospheric Administration, Office of

Oceanography and Marine Assessment, Rockville, Maryland. 81 pp.

NOAA, 1987. National status and trends program for marine environmental quality - Progress Report: A summary of selected data on chemical contaminants in tissues collected during 1984, 1985, 1986, and 1987. NOAA Technical Memorandum NOS OMA 38 Rockville, Maryland. 62pp.

NOAA, 1988. National status & trends program for marine environmental quality progress report: A summary of selected data on chemical contaminants in sediments collected during 1984, 1985, 1986, and 1987. NOAA Technical Memorandum NOS OMA 44 Rockville, Maryland. 54 pp.

NOAA, 1989. National status & trends program for marine environmental quality progress report: A summary of data on tissue contamination from the first three years (1986-1988) of the mussel watch project. NOAA Technical Memorandum NOS OMA 49 Rockville, Maryland. 151 pp.

Patel, B., V.S. Bangera, S. Patel, and M.C. Balani, 1985. Heavy Metals in the Bombay Harbor area. Marine Pollution Bulletin. 16(1):22-28.

Pierce, D.E., and A.B. Howe, 1977. A further study on winter flounder group identification off Massachusetts. Transactions of the American Fisheries Society. 106(2):131-139.

Reid, R.N., J.E. O'Reilly, and V.S. Zdanowicz, (Eds.), 1982. Contaminants in New York Bight and Long Island Sound sediments and demersal species, and contaminant effects on benthos, Summer 1980. NOAA Technical Memorandum NMFS-F/NEC-16, 97 pp.

Roberts, A.E., D.R. Hill, and E.C. Tifft, Jr., 1982. Evaluation of New York Bight lobsters for PCBs, DDT, petroleum hydrocarbons, mercury, and cadmium. Bulletin of Environmental Contamination and Toxicology. 29:711-718.

Steimle, F.W., P.D. Boehm, V.S. Zdanowicz, and R.A. Bruno, 1986. Organic and trace metal levels in ocean quahog, *Arctica islandica linne*, from the northwestern Atlantic. Fishery Bulletin: Vol 84, No.1, pp. 133-140.

USEPA, 1988. A histopathological and chemical assessment of winter flounder, lobster and soft-shelled clam indigenous to Quincy Bay, Boston Harbor and an in situ evaluation of oysters including sediment (surface and

cores) chemistry (G.R. Gardner & R.J. Pruell, Principal Investigators). U.S. Environmental Protection Agency, Environmental Research Laboratory, South Ferry Road, Narragansett, Rhode Island 02882. 120 pp.

USEPA, 1989. Assessing human health risks from chemically contaminated fish and shellfish: a guidance manual. U.S. Environmental Protection Agency, Office of Marine and Estuarine Protection (WH-556F), Washington, D.C. 20460. 91 pp. with appendices.

USFDA, 1988. Lead, cadmium, and other elements in domestic shellfish: Summary of FY'85/86 field program (S.G. Capar, Principal Investigator). U.S. Food and Drug Administration, Division of Contaminants Chemistry, Center for Food Safety and Applied Nutrition, Washington, D.C. 35 pp.

Wallace, G.T., R.P. Eganhouse, L.C. Pitts, and B.R. Gould, 1988. Analysis of contaminants in marine resources. prepared by the Massachusetts Department of Environmental Quality Engineering Division of Water Pollution Control and the United States Environmental Protection Agency, 176 pp.

Weis, J.S., and P. Weis, 1989. Effects of environmental pollutants on early fish development. Reviews in Aquatic Sciences. 1(1):45-73.

APPENDIX A

Analytical procedures for trace metal analysis.

APPENDIX A-1

Wet Tissue Digestion Procedure for Total Metals Analysis

Chemicals:

1) HNO_3 70.0 - 71.0% n Baker Instra-Analyzed Reagent for Trace Metal Analysis.

2) H_2O_2, 30% 'Baker Analyzed' Reagent.

1. Weigh approximately 10 grams of blended tissue sample in a preweighed or tared tall form beaker (200ml). Record sample wet weight to nearest 0.01 grams.

2. Add 10 ml concentrated HNO_3 to sample in the tall form beaker. Cover with a watch glass and let sit overnight (15 to 16 hours) in ventilated fume hood to cold digest.

3. Place covered samples on a steam bath until almost all tissue is digested. At this time spike the appropriate quality control samples with a standard spike solution containing concentrations as listed below for the particular species being digested.

Analyte	Finfish	Lobster	Shellfish
	ppm	ppm	ppm
Pb	4.0	4.0	4.0
Zn	10.0	50.0	20.0
Cu	10.0	50.0	2.0
Cr	1.0	1.0	1.0
Cd	0.5	0.5	0.5

(All standard solutions made in 2% v/v HNO_3)

Use of these standard spike solutions will result in the enrichment values listed below for the final 50 mL volume of spiked digestate.

Analyte	Finfish	Lobster	Shellfish
	ppm	ppm	ppm
Cd	0.05	0.05	0.05
Cr	0.10	0.10	0.10
Cu	1.00	5.00	0.20
Pb	0.40	0.40	0.40
Zn	1.00	5.00	2.00

4. Reflux the samples for 2 hours.

5. Remove watch glass after 2 hours of refluxing and evaporate sample to near dryness.

6. Once all samples are evaporated to near dryness and are at room temperature, add 10 ml concentrated HNO_3 and 10 ml of 30% H_2O_2 to each sample. Cover beaker with watch glass and let sit overnight (15 to 16 hours).

7. Place covered samples on cold steam bath and slowly bring up to temperature. (Watch for violent reactions.) Reflux for 2 hours on steam bath.

8. Remove watch glass and evaporate to near dryness.

9. Add approximately 20 ml of a 2% v/v hot HNO_3 solution to beaker and let heat for 5 minutes on steam bath.

10. Remove beaker from steam bath, wipe off any moisture on the outside of beaker and filter the sample using a glass filter funnel with a Reeve Angel 802 12.5 cm fluted filter paper or equivalent. Collect filtrate in 50 ml volumetric flask. Rinse beaker with two aliquots of 5-10 ml hot 2% v/v HNO_3 solution. Rinse down filter paper with hot 2% HNO_3 to remove as much yellow coloring as possible from the filter paper. Remove filter paper and rinse glass funnel with hot 2% HNO_3 taking care not to go over the 50 ml mark.

11. Q.S. to 50 ml with 2% v/v HNO_3 and transfer to sample containers.

12. Sample digestate is then analysed for metals on a Perkin Elmer AAS 3030B according to the manufacturer's specifications.

APPENDIX A-2

Mercury Digestion Method

Solutions needed:

1) 5% Potassium permanganate solution : Dissolve 25 g $KMnO_4$ in deionized distilled water and dilute to 500 ml.

2) 5% Potassium persulfate solution : Dissolve 25 g $K_2S_2O_8$ in deionized distilled water and dilute to 500 ml.

Procedure for Fin Fish and Lobster Tissue Digestion

1) Weigh approximately 1 gram of blended sample to the nearest 0.1 mg in a pre-weighed or tared 125 ml Erlenmeyer reaction flask.

2) Add 5.0 ml conc. H_2SO_4 and 2.5 ml conc. HNO_3 to each flask and place in a 70°C water bath.

3) Remove samples to be spiked from the water bath when a colored liquid with no visible tissue has formed. Spike appropriate Q.C. samples with 0.5 ml of 100 ng/ml Hg for a 50 ng Hg enriched spike reading. Return samples to water bath.

4) Samples should remain in the water bath for four (4) hours.

5) Ice samples.

6) Add 10 ml $KMnO_4$ solution to each flask and let stand 15 minutes in ice bath.

7) Add 8 ml $K_2S_2O_8$ solution to each flask while still in the ice bath.

8) Add 0.5 - 1.5 g of $KMnO_4$ crystals as needed to keep the solution purple. Remove from ice bath. Samples are left overnight to digest or are placed in a 70°C water bath for 2 to 4 hours. Please note, solutions must remain purple until analysis. Analysis must be within 24 hours.

APPENDIX A-3

Mercury Digestion Method

Chemicals:

1) HNO_3, 70.0-71.0%, 'Baker Instra-Analyzed' Reagent for Trace Metal Analysis

2) H_2SO_4, 95.0-98.0%, 'Baker Instra-Analyzed' Reagent for Trace Metal Analysis

3) $KMnO_4$, 'Baker Instra-Analyzed' Reagent for Hg Determination

4) $K_2S_2O_8$, 'Baker Instra-Analyzed' Reagent for Hg Determination

Solutions needed:

1) 5% Potassium permanganate solution : Dissolve 25 g $KMnO_4$ in deionized distilled water and dilute to 500 ml.

2) 5% Potassium persulfate solution : Dissolve 25 g $K_2S_2O_8$ in deionized distilled water and dilute to 500 ml.

Procedure for Shellfish Tissue Digestion

1) Weigh approximately 2 grams of blended sample, to the nearest 0.1 mg, in a pre-weighed or tared 125 ml Erlenmeyer reaction flask.

2) Add 7.0 ml conc. H_2SO_4 and 3.0 ml HNO_3 to each flask and place in a 70°C water bath.

3) Remove samples to be spiked from water bath when a colored liquid with no visible tissue has formed. Spike appropriate Q.C. samples with 1.0 ml of 100 ng/ml Hg. This will yield 50 ng Hg enrichment in final sample (refer to step 8). Return samples to water bath.

4) Samples should remain in the water bath for four (4) hours.

5) Remove samples from water bath. Allow to cool to room temperature. Add 5.0 mL deionized distilled water to the samples to cause precipitation of waxy digestion products and decrease the acidity of the sample solutions.

6) Filter samples through VWR grade 615 9 cm or equivalent filter paper into a stoppered glass 25.0 mL graduated cylinder to remove the waxy precipitate. Rinse the sample flask twice with small amount of 20% v/v HNO_3. Rinse filter paper with small amount of 20% HNO_3 taking care not to exceed 25.0 mL of liquid in cylinder.

7) Q.S. to 25.0 mL with 20% HNO_3. Stopper cylinder and shake well.

8) Using acid washed disposable 9 inch Pasteur pipets, divide sample into two equal portions and place in two clean 125 mL Erlenmeyer flasks. Rinse cylinder with two 2.5 mL portions of 20% HNO_3 solution, divide rinses equally between the two sample flasks.

9) Ice samples.

10) Add 10 mL $KMnO_4$ solution to each flask and let stand 15 minutes in ice bath.

11) Add 8 mL $K_2S_2O_8$ solution to each flask while still in the ice bath.

12) Add 0.5 - 1.5 g of $KMnO_4$ crystals as needed to keep the solutions purple. Remove from ice bath. Samples are left overnight to digest or are placed in a 70°C water bath for 2 to 4 hours. Please note, solutions must remain purple until analysis. Analysis must be within 24 hours.

APPENDIX A-4

Washing Procedure for all Labware used for Metals Analysis

1. A 12 hour presoak is used if glassware has an organic/waxy film. The presoak solution is made from Terg-A-Zyme (as instructions indicate on the carton).

2. Wash with soap (Liquinox) and tap water, rinse well with tap water.

3. Rinse thoroughly with 1:1 HNO_3 followed by 1:1 H_2SO_4 (twice). A squeeze bottle is used to deliver the rinse.

4. Rinse thoroughly with de-ionized distilled water at least three times. The de-ionized distilled water should have a resistance of 2Mohm or higher.

5. Air dry or place in oven to dry.

6. Store clean labware in assigned areas, covering with parafilm or glass stoppers, whichever is appropriate.

APPENDIX B

Maps of station numbers and locations.

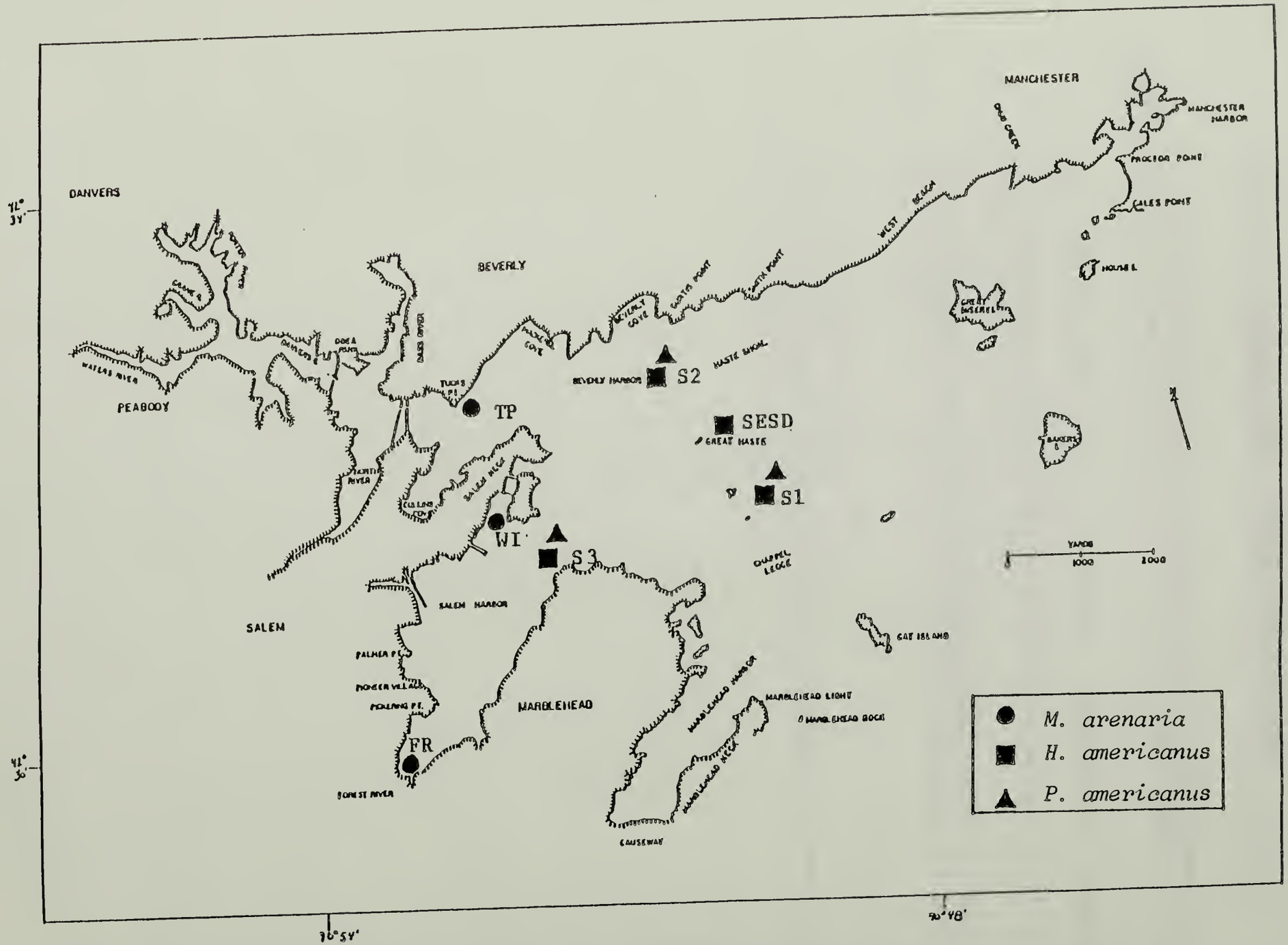


Figure B-1. Salem Harbor station locations and numbers.

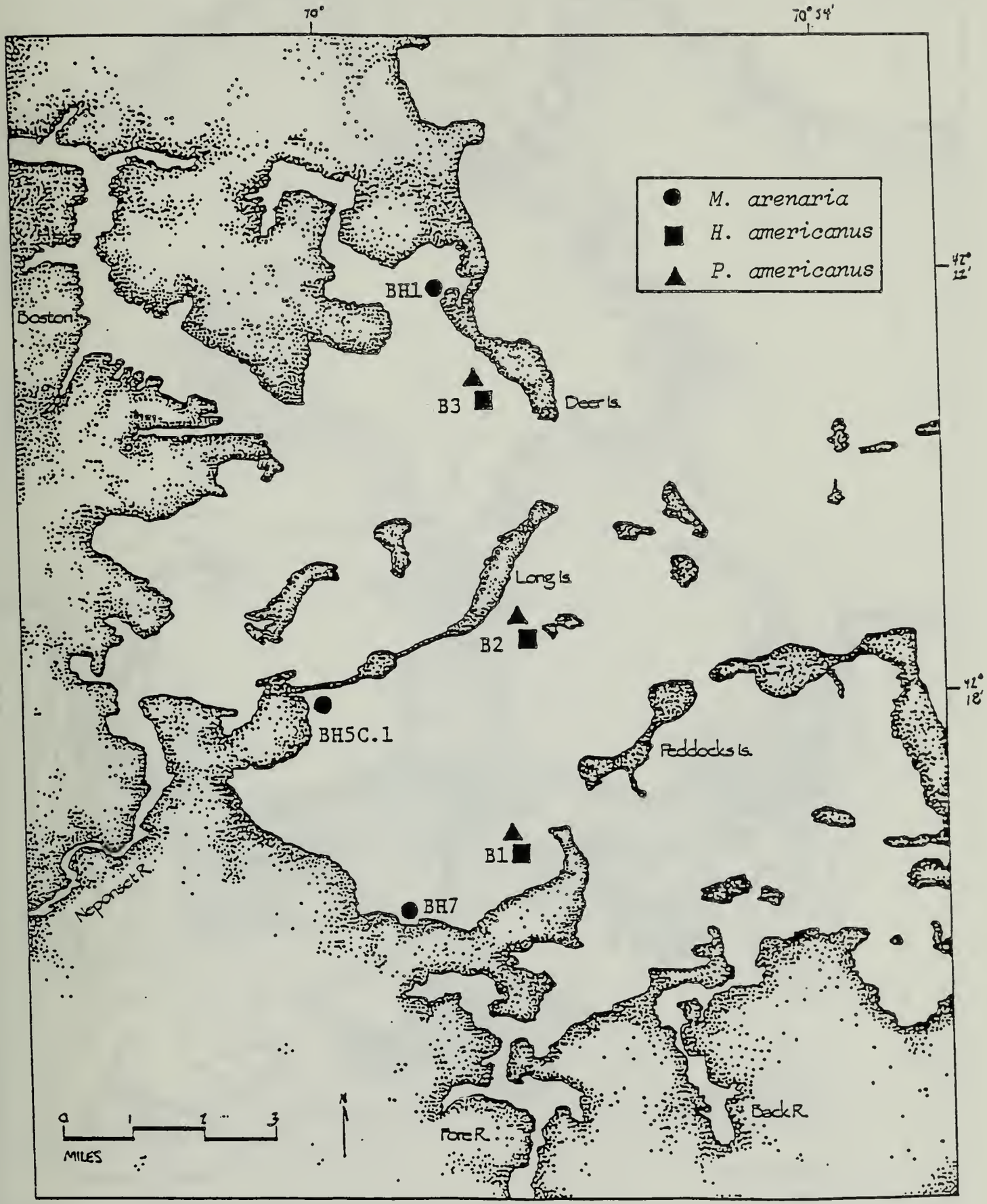


Figure B-2. Boston Harbor station locations and numbers.

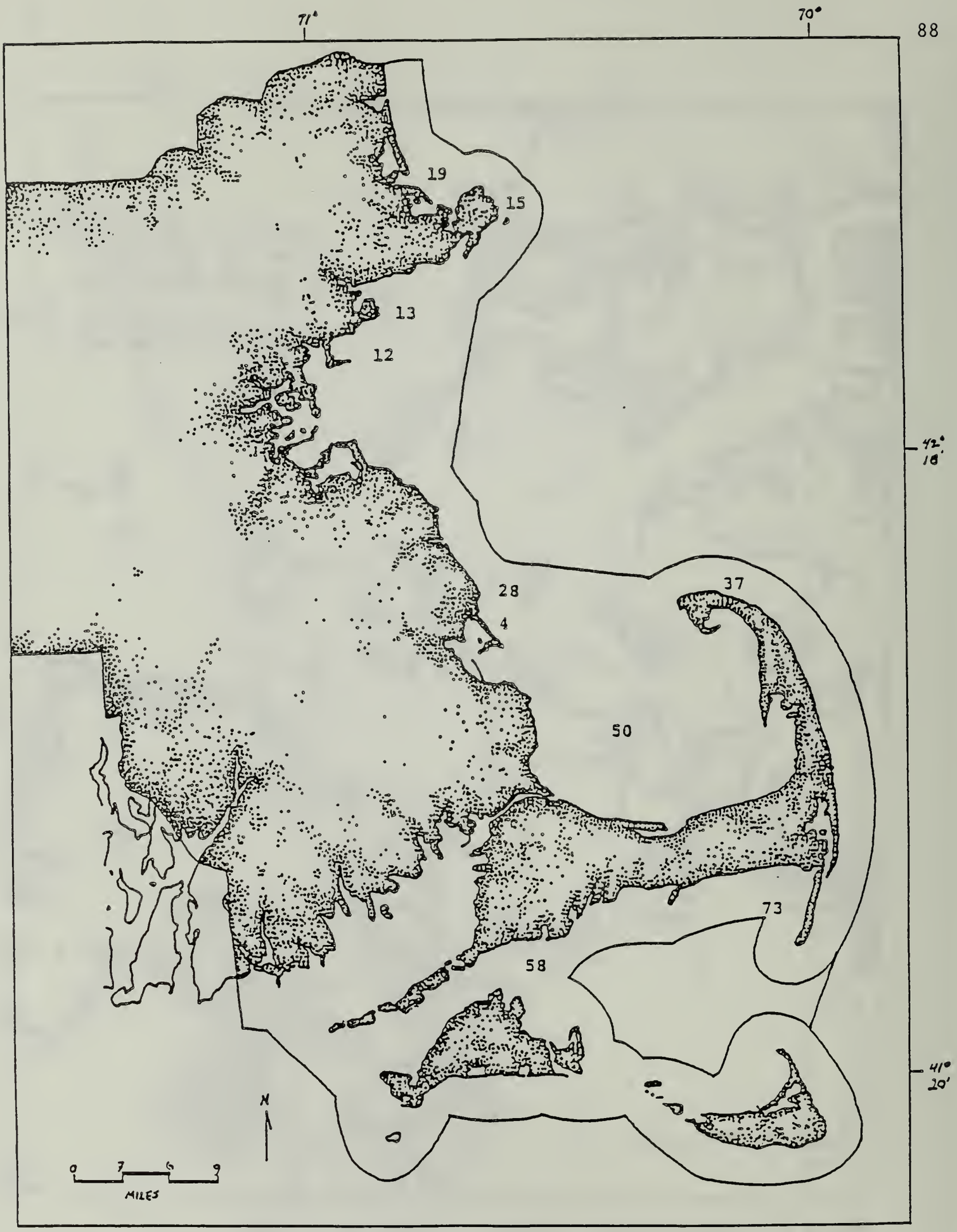


Figure B-3. Cruise 8491 (Spring, 1984) coastal sample station numbers and locations.

Figure B-4. Cruise 8492 (Fall, 1984) coastal sample station numbers and locations.

Figure B-5. Cruise 8591 (Spring, 1985) coastal sample station numbers and locations.

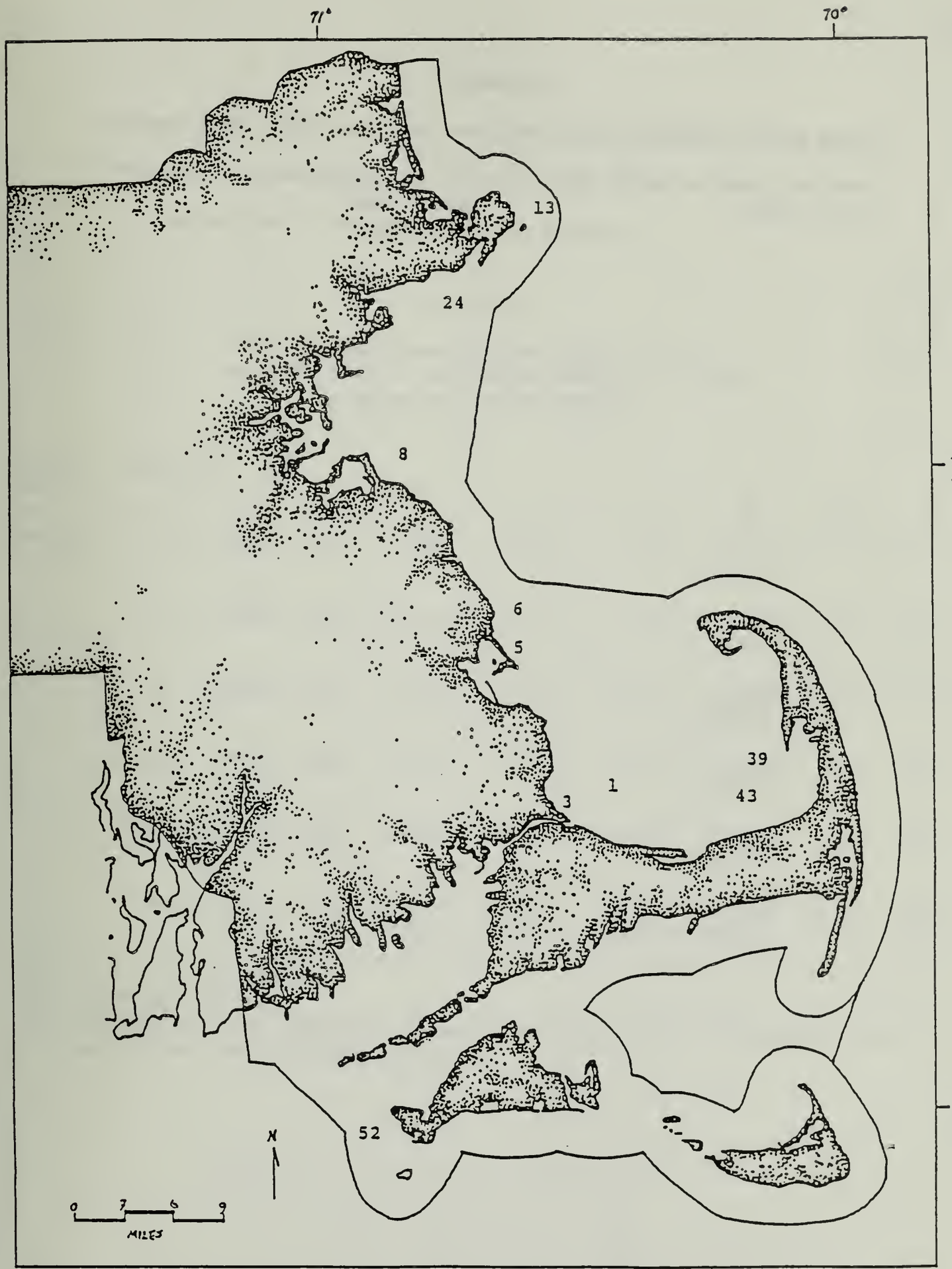


Figure B-6. Cruise 8592 (Fall, 1985) coastal sample station number and locations.

APPENDIX C

Trace metal concentrations (μg/g wet wt.) for individual samples.

Data for samples which were analyzed in replicate are presented in the form:

$$\frac{\text{sample mean}}{\text{standard deviation/number of replicates}}$$

Table C-1

Trace metal concentrations (μg/g wet wt.)
for Soft Shell Clam, *Mya arenaria*, collected
in Salem and Boston Harbors.

Cruise/ date	Station[c] #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
9Apr86	TP	PM1024 (12)	0.091	0.86	2.16	0.027[a] 0.004/4	0.53	11.0
	WI	PM1025 (12)	0.044	0.73	3.39	0.016[b] 0.002/2	0.44	14.3
	FR	PM1026 (12)	0.071	0.76	3.07	0.027[b] 0.001/2	0.90	15.4
	BH7	PM1029 (12)	0.039	0.34	4.40	0.022[b] 0.001/2	0.73	14.2
	BH5C.1	PM1028 (12)	0.038	0.47	5.90	0.026[b] 0.001/2	1.18	15.4
	BH1	PM1027 (12)	0.032 0.003/3	0.19 0.01/3	5.07 0.09/3	0.026[b] 0.002/2	<0.27	16.8 0.1/3

(a) 72.4-77.0% Hg recovery
(b) 77.0% Hg recovery
(c) Stations TP, WI, and FR are Salem Harbor stations; stations BH7, BH5C.1, and BH1 are Boston Harbor stations.

Table C-2

Trace metal concentrations (μg/g wet wt.) for Surf Clam (*Spisula solidissima*), and Blue Mussel (*Mytilus edulis*), collected during Resource Assessment Cruise 8491, 8492, 8591, and 8592.

Surf Clam (*S. solidissima*)

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	37	P872 (2)	0.07 0.02/3	0.87 0.03/3	4.80 0.14/3	<0.021[a]	0.22 0.11/3	15.0 0.4/3
8591/ 6-22May85	37	P860 (1)	0.033 0.005/3	0.13 0.03/3	0.71 0.06/3	0.025[b] 0.007/4	<0.20	6.77 0.85/4
	47	P861 (2)	0.056	0.27	1.51	0.083[b] 0.008/4	0.24	13.0
	86	P862 (2)	0.049 0.013/6	0.21 0.04/6	1.38 0.14/6	0.016[b] 0.000/2	<0.20	11.2 0.31/6
8592/ 3-19Sep85	39	P923 (2)	0.032 0.006/3	0.10 0.01/3	0.68 0.05/3		<0.20	4.87 0.35/4
	39	P924 (1)	<0.020	0.46 0.04/6	1.15 0.04/6	<0.008[b]	<0.20	6.33 0.23/6
	39	P925 (1)	<0.020	0.79 0.09/3	1.95 0.10/3		<0.20	7.10 0.24/4

Blue Mussel (*M. edulis*)

Cruise/ Date	Station #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	12	P875 (6)	0.33	0.73	6.42		2.71	27.7
	73	P856 (8)	0.180	0.16	5.54 0.18/2	<0.008[c]	0.65 0.09/2	13.3
8492/ 10-27Sep84	34	P874 (5)	0.22	0.20	1.61		0.31	22.2
8592/ 3-19Sep85	24	P927 (18)	0.300	0.66	3.90	0.016[d] 0.003/2	3.38	27.4

(a) 90.1% Hg recovery
(b) 72.4-77.0% Hg recovery
(c) 80.7% Hg recovery
(d) 72.4% Hg recovery

Table C-3

Trace metal concentrations (μg/g wet wt.)
for Ocean Quahog, *Arctica islandica*, collected
during Resource Assessment Cruise
8491, 8492, 8591, and 8492.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg[a]	Pb	Zn
8491/ 7-22May84	28	P873	0.40 0.03/3	0.86 0.02/3	5.46 0.36/3		1.9 0.1/3	14.3 0.3/3
	50	P880	0.280 0.024/3	0.25 0.03/3	2.54 0.04/3		1.5 0.33/3	9.73 0.97/3
8492/ 10-27Sep84	3	P857	0.341 0.009/3	0.89 0.52/4	2.77 0.07/4	0.011 0.001/2	3.46 0.10/4	10.2 0.28/3
8591/ 6-22May85	6	P863	0.214	0.82	2.5	0.133 0.005/2	1.7	12.1
	42	P859		0.68	2.20		1.08	
	43	P926	0.236	0.29	0.92	<0.008	0.53	7.75
8592/ 3-19Sep85	1	P920	0.291	0.80	2.06	0.016 0.004/6	1.72	8.30

(a) 72.4% Hg recovery

Table C-4

Trace metal concentrations (μg/g wet wt.) for American Lobster, *Homarus americanus*, collected in Salem Harbor.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
1June84	SESD	P943	0.357 0.034/3	0.43 0.04/3	24.7 1.6/3	0.118[c] 0.011/3	0.05 0.05/3	23.3 0.8/3
	SESD	P944	0.048 0.002/3	0.86 0.00/3	19.3 0.3/3	0.112[c] 0.003/3	0.03 0.03/3	22.7 0.1/3
	SESD	P945	0.092 0.003/3	0.31 0.01/3	18.9 0.6/3	0.228[c] 0.008/3	0.23 0.14/3	31.3 0.1/3
	SESD	P956	0.053 0.014/3	0.24 0.01/3	13.3 0.7/3	0.190[c] 0.020/3	0.08 0.03/3	22.5 0.5/3
	SESD	P957	0.080 0.038/3	0.26 0.01/3	17.1 1.7/3	0.119[c] 0.30/3	0.13 0.13/3	25.5 0.2/3
19Nov85	S1	P941	0.136	1.04	21.1	0.060[a]	0.18	20.6
	S1	P942	0.674	0.13	13.8	0.097[a]	<0.11	15.4
11Apr86	S2	PM1016	0.187	0.20	28.6	0.101[a] 0.006/3	<0.72	34.8
	S2	PM1017	0.277 0.013/3	0.56 0.03/3	24.6	0.078[a]	<0.72	30.6 0.7/3
	S2	PM1018	0.189	0.52	23.5	0.073[a]	<0.72	25.3
	S3	PM1019	0.474	0.10	23.6 1.7/3	0.185[b] 0.001/3	<0.72	21.5
	S3	PM1020	0.424	0.14	23.1	0.149[b]	<0.72	31.3
	S3	PM1021	0.129	0.24	27.0	0.124[b]	<0.72	20.9

(continued)

Table C-4 (continued)

Trace metal concentrations (μg/g wet wt.)
for American Lobster, *Homarus americanus*,
collected in Salem Harbor.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
15Dec86	S2	PM1293	0.070	0.50	16.5	0.101[b]	<0.72	24.4
	S2	PM1294	0.115	1.24	21.9	0.083[b]	<0.72	23.7
	S2	PM1297	0.078	1.03	20.8	0.177[b]	<0.72	21.9
	S3	PM1285	0.177	0.17	20.5	0.100[b]	<0.72	19.6
	S3	PM1286	0.263	0.95	22.1	0.131[b]	<0.72	24.6
	S3	PM1289	0.183	0.31	16.9	0.059[b]	<0.72	21.0

(a) 63.2% Hg recovery
(b) 55.3% Hg recovery
(c) 88.0% Hg recovery

Table C-5

Trace metal concentrations (μg/g wet wt.)
for American Lobster, *Homarus americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg	Pb	Zn
9Apr86	B2	P981	0.031	0.20	26.7	0.188[a]	<0.21	36.1
	B2	P982	<0.011	0.10	22.0		<0.21	24.2
	B2	P983	0.121	0.10	43.0	0.214[a]	<0.21	25.6
	B2	P984	0.296	0.30	40.3		<0.21	32.9
	B2	P985	0.157	0.20	31.9	0.160[a]	<0.21	24.7
19Dec86	B1	PM1303	0.127	<0.06	18.9	0.159[b]	0.49	28.6
	B1	PM1304	0.314	0.15	20.1	0.163[b]	0.40	29.6
	B1	PM1305	0.102	0.10	17.8	0.125[b]	<0.27	29.3
	B2	PM1313	0.114 0.010/3	0.07 0.03/3	18.1 0.4/3	0.143[b]	<0.27	27.1 0.2/3
	B2	PM1314	0.203	0.10	30.0	0.151[b]	0.50	25.6
	B2	PM1315	0.097	0.14	19.5	0.113[b] 0.008/3	0.34	24.4
	B3	PM1290	0.156	<0.06	24.0	0.135[b]	0.34	25.3
	B3	PM1291	0.254	<0.06	43.2	0.204[b]	0.63	33.7
	B3	PM1292	0.170	<0.06	21.0	0.176[b]	0.46	25.7

(a) 63.2% Hg recovery
(b) 55.3% Hg recovery

Table C-6

Trace metal concentrations (μg/g wet wt.) for American Lobster, *Homarus americanus*, collected during Resource Assessment Cruise 8491, 8492, 8591, and 8592.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg[a]	Pb	Zn
8491/ 7-22May84	13	P885	0.360	0.16 0.09/2	33.9 1.00/2	0.131 0.013/3	<0.21	41.3
	15	P888	0.450	0.09 0.05/2	26.6 3.8/2	0.131	<0.21	41.4
	15	P889	0.440	0.25 0.23/2	26.2 0.07/2	0.149	<0.21	40.4
	19	P886	0.690	0.16 0.08/4	28.9 3.5/4	0.167	<0.21	34.6
8492/ 10-27Sep84	1	P858	0.159	0.38 0.35/2	19.6 0.07/2	0.155	0.28 0.08/2	20.8
	2	P867	0.831 0.061/4	0.22 0.03/4	27.7[b] 0.56/4	0.178	<0.68	38.0
	3	P869	0.281	0.11	32.4		0.14	29.3
	5	P887		0.18	32.5		0.24	
	18	P868	0.461 0.016/5	0.06 0.03/5	19.4 2.7/5	0.289	<0.68	34.6
8591/ 6-22May85	4	P866	0.102 0.006/4	0.15 0.01/4	22.0[b] 2.4/4	0.052	<0.68	29.6
	5	P870	0.378	0.08	19.1	0.207	<0.11	27.7
	9	P865	0.490 0.027/4	0.07 0.04/4	41.6	0.109	<0.68	27.9
	22	P871	0.257	0.17	36.7		0.19	38.3
	27	P864	0.176 0.007/5	0.14 0.02/5	45.3		<0.68	32.7

(continued)

Table C-6 (continued)

Trace metal concentrations (μg/g wet wt.) for American Lobster, *Homarus americanus*, collected during Resource Assessment Cruise 8491, 8492, 8591, and 8592.

Cruise/ date	Station #	Lab #	Cd	Cr	Cu	Hg[a]	Pb	Zn
8592/ 3-19Sep85	3	P915	0.120	0.09	26.9	0.109	0.37	22.6
	3	P916	0.233	0.08	18.0		<0.11	21.0
	5	P917	0.162	0.07	37.8		<0.11	19.6
	5	P918	0.247	0.07	30.6		<0.11	16.0
	6	P913	0.473	0.04	33.2	0.112	<0.11	28.9
	6	P914	0.306	0.06	31.1		<0.11	21.1
	8	P911	0.223	0.07	41.4		0.14	19.2
	8	P912	0.336	0.10	56.8		<0.11	25.0
	13	P919	0.645	0.08	20.9	0.081	0.14	22.8

(a) 63.2% Hg recovery
(b) 51.5% Cu recovery

Table C-7

Trace metal concentrations (μg/g wet wt.)
for Winter Founder, *Pseudopleuronectes americanus*,
collected in Salem Harbor.

Cruise/ date	Station #	Lab[1] #		Cd	Cr	Cu	Hg	Pb	Zn
19Nov85	S1	P946		<0.011	<0.01	0.13	0.027[a] 0.004/2	<0.11	7.00
11Apr86	S1	PM1009	*	<0.015	0.03 0.03/3	0.22 0.03/3	0.086[a] 0.00/2	<0.17	3.82 0.42/3
	S1	PM1010	*	<0.015	0.08 0.03/3	0.20 0.00/3	0.072[a] 0.001/2	<0.17	4.02 0.22/3
	S1	PM1011	*	0.020	<0.08 -/3	0.17 0.03/3	0.029[a] 0.005/2	<0.17	4.16 0.35/3
	S1	PM1012	*	0.019	0.09	0.32		<0.30	5.60
	S1	PM1013	*	0.020	0.10	0.35		0.45	4.31
	S2	PM997	*	<0.011	0.10	0.20	0.085[b] 0.042/2	<0.21	4.30
	S2	PM998	*	<0.011	0.09	0.24		<0.21	4.20
	S2	PM999	*	<0.011	0.39	0.20	0.024[b] 0.013/2	<0.21	4.50
	S2	PM1000	*	<0.011	0.15	0.20		<0.21	7.19
	S2	PM1001	*	<0.011	0.10	0.15	0.057[b] 0.008/2	<0.21	4.09
	S2	PM1002	*	<0.011	0.09	0.22		<0.21	4.40
	S3	PM1003	*	<0.011	0.04	0.26	0.038[a] 0.001/2	<0.21	5.39
	S3	PM1004	*	<0.011	0.09	0.36	0.031[a] 0.006/2	<0.21	4.72

(continued)

Table C-7 (continued)

Trace metal concentrations (μg/g wet wt.)
for Winter Founder, *Pseudopleuronectes americanus*,
collected in Salem Harbor.

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
	S3	PM1005 *	<0.011	0.09	0.24	0.060[a]	<0.21	5.54
						0.011/2		
	S3	PM1006 *	0.018	<0.08	0.29		<0.17	4.42
				-/3	0.05/3			0.41/3
	S3	PM1007 *	0.018	0.10	0.24		0.18	4.71
				0.01/3	0.01/3			0.02/3
	S3	PM1008 *	<0.015	0.08	0.25		<0.17	4.42
				0.04/2	0.00/2			0.04/2
15Dec86	S2	PM1275	<0.011	0.06	0.30		<0.17	5.40
				0.02/3	0.03/3			0.49/3
	S2	PM1276	<0.011	0.05	0.25	0.032[b]	<0.17	4.04
						0.018/2		
	S2	PM1277	<0.011	0.05	0.24		0.39	3.41
	S3	PM1278	0.014	0.05	0.24	0.024[b]	0.38	4.33
						0.008/4		
	S3	PM1279	0.020	0.07	0.17	0.024[b]	<0.17	3.69
				0.03/3	0.03/3	0.001/2		0.36/3

(1) The * denotes that the sample was not homogenized.
(a) 47.3-75.1% Hg recovery
(b) 60.0-81.4% Hg recovery

Table C-8

Trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
21Nov85	B3	P951	0.019	0.05	0.23	0.028[a] 0.011/2	0.00	4.68
	B3	P952	0.014	0.10	0.23	0.150[a] 0.025/2	0.00	6.00
	B3	P953	<0.011	0.09	0.23	0.061[a] 0.013/2	0.00	6.13
	B3	P954	0.028	0.05	0.18	0.091[a] 0.004/2	0.00	5.72
	B3	P955	0.034	0.10	0.29	0.105[b] 0.001/3	0.00	5.41
9Apr86	B1	P975 *	0.017	0.04	0.30		<0.21	10.2
	B1	P976 *	<0.011	0.05	0.28		<0.21	6.13
	B1	P977 *	0.020	0.05	0.29	0.141[c] 0.048/2	<0.21	7.09
	B1	P978 *	0.017	0.04	0.21		<0.21	9.78
	B1	P979 *	<0.011	0.09	0.22	0.089[c] 0.020/2	<0.21	5.71
	B1	P980 *	<0.011	0.10	0.28	0.154[c] 0.022/2	<0.21	6.42
	B2	P969	0.012	<0.01	0.36	0.187[a] 0.024/4	0.00	7.20
	B2	P970	0.014	0.05	0.23	0.101[a] 0.022/4	0.05	9.91
	B2	P971	0.021	0.00	0.21		0.00	7.80

(continued)

Table C-8 (continued)

Trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
	B2	P972	0.027	0.05	0.27		0.09	7.93
	B2	P973	0.024	<0.01	0.19	0.056[c] 0.009/2	0.00	6.69
	B2	P974	0.015 0.020/4	0.04 0.02/4	0.25 0.06/4		<0.21	6.00 1.50/4
	B3	P963	0.014	0.10	0.24		0.00	6.57
	B3	P964	0.022	0.04	0.36		0.40	8.50
	B3	P965	0.020	0.05	0.54	0.089[c] 0.018/2	0.00	6.82
	B3	P966	<0.011	0.05	0.38		0.08	9.60
	B3	P967	0.013	0.04	0.21	0.085[c] 0.093/2	0.00	7.82
	B3	P968	<0.011	<0.01	0.19	0.137[c] 0.025/4	0.00	7.14
19Dec86	B1	PM1298	0.015	0.05	1.49	0.114[c] 0.035/2	<0.30	5.16
	B1	PM1299	0.014	0.05	0.19	0.115[c] 0.036/4	<0.30	7.19
	B1	PM1300	<0.011	0.05	0.20	0.091[c] 0.019/2	<0.30	6.93
	B1	PM1301	0.015	0.05	0.15		<0.30	4.48
	B2	PM1308	<0.029	<0.08	0.34		<0.72	6.02
	B2	PM1309	<0.029	<0.08 -/3	0.30 0.09/3	0.115[d]	<0.72	6.54 0.39/3

(continued)

Table C-8 (continued)

Trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
	B2	PM1310	<0.029	<0.08	0.19	0.171[d]	<0.72	4.77
	B2	PM1311	<0.029	<0.08	0.15	0.186[d] 0.010/3	<0.72	5.43
	B3	PM1281	0.019	0.05	0.15	0.020[c]	<0.30	4.74
	B3	PM1282	0.014	0.09	0.14	0.025[c] 0.003/2	<0.30	4.76
	B3	PM1283	<0.011	0.10	0.25		<0.30	4.67
	B3	PM1284	<0.011	0.05	0.28	0.032[c] 0.004/4	<0.30	4.04

(1) The * denotes that the sample was not homogenized.
(a) 47.3-75.1% Hg recovery
(b) 84.6% Hg recovery
(c) 60.0-81.4% Hg recovery
(d) 47.3% Hg recovery

Table C-9

Trace metal concentration (μg/g wet weight)
for Winter Flounder, *Pseudoeleuronectes americanus*,
collected during Resource Assessment Cruise
8491, 8492, 8591, and 8592

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	4	P876 *	0.000	0.02 0.00/2	0.14 0.11/2		0.00	5.15 0.21/2
	4	P881 *	0.014	0.16	0.36		0.59	10.2
	19	P877 *	0.000	0.02 0.01/3	0.17 0.05/3	0.056[a] 0.004/3	0.02 0.03/3	9.82 0.27/3
	19	P882 *	0.010 0.000/3	0.05 0.00/3	0.23 0.01/3		0.10 0.05/3	11.8 0.4/3
	58	P878 *	0.008 0.003/3	0.07 0.04/3	0.33 0.03/3	0.021[b] 0.001/3	0.16 0.15/3	7.99 0.46/3
	58	P883 *	0.009 0.000/3	0.05 0.01/3	0.28 0.02/3	0.027[a] 0.001/3	0.25 0.23/3	6.73 0.39/3
8492/ 10-27Sep84	21	P853 *	0.018 0.016/3	0.09 0.01/5	0.32 0.04/4		<0.54	8.02 3.12/3
	21	P854 *	0.015	0.05 0.05/5	0.27 0.06/5	0.035[c]	<0.21	7.37 1.38/4
	35	P855 *	<0.018	0.03 0.02/4	0.24 0.03/4		<0.54	6.93 1.26/3
	37	P884 *	<0.018	0.03 0.03/4	0.36 0.11/4	0.033[c]	<0.54	6.97 0.73/3
	37	P879 *	0.088 0.003/3	0.04 0.00/3	0.20 0.03/3	0.027[a] 0.002/2	0.20 0.16/3	5.98 0.51/3
8591/ 6-22May85	60	P849	0.039 0.000/2	0.12 0.03/3	0.57 0.03/3	0.096[d] 0.003/3	<0.54	8.80 0.48/2
	60	P850		0.12	0.45	0.076[d] 0.004/3	<0.11	
	63	P847		0.17	0.42	0.065[d] 0.013/3	<0.11	

(continued)

Table C-9 (continued)

Trace metal concentration (μg/g wet weight)
for Winter Flounder, *Pseudoeleuronectes americanus*,
collected during Resource Assessment Cruise
8491, 8492, 8591, and 8592

Cruise/ date	Station #	Lab[1] #	Cd	Cr	Cu	Hg	Pb	Zn
	63	P848	0.019	0.14 0.05/2	0.43	0.065[d] 0.005/3	0.34	7.29
	81	P851 *	0.015	0.04 0.06/2	0.42 0.10/2	0.065[d] 0.004/3	0.56 0.59/2	6.28
	81	P852 *	0.038 0.011/2	0.24 0.07/3	0.48 0.17/3		<0.54	8.53 1.14/2
8592/ 3-19Sep85	8	P930	<0.011	0.03	0.13		0.13	5.63
	8	P931	<0.011	0.08	0.27	0.034[c]	0.15	5.15
	43	P928	<0.011	0.00	0.18		<0.11	4.55
	43	P929	<0.011	0.04	0.21	0.016[c]	<0.11	5.08
	52	P921	<0.011	0.06	0.37		<0.11	4.49
	52	P922	<0.011	0.00	0.23	0.018[c]	<0.11	4.72

(1) The * denotes that the sample was not homogenized.
(a) 90.1% Hg recovery
(b) 90.1-106.1% Hg recovery
(c) 47.3% Hg recovery
(d) 84.6% Hg recovery

APPENDIX D

Station average trace metal concentrations (µg/g wet wt.).

Data is presented in the form:

station mean
standard deviation/number of samples analyzed

Where only a sample mean is presented, replicate samples were not available for analysis.

Table D-1

Mean trace metal concentrations (μg/g wet wt.)
for Soft Shell Clam, *Mya arenaria*, collected
in Boston and Salem Harbors.

Cruise/ date	Station[a] #	Cd	Cr	Cu	Hg	Pb	Zn
9Apr86	TP	0.091	0.86	2.16	0.027	0.53	11.0
	WI	0.044	0.73	3.39	0.016	0.44	14.3
	FR	0.071	0.76	3.07	0.027	0.90	15.4
	B1	0.039	0.34	4.40	0.022	0.73	14.2
	B2	0.038	0.47	5.90	0.026	1.18	15.4
	B3	0.032	0.19	5.07	0.026	<0.27	16.8

(a) Stations TP, WI, and FR are Salem Harbor stations; stations B1, B2, and B3 are Boston Harbor stations.

Table D-2

Mean Trace metal concentrations (μg/g wet wt.)
for Surf Clam (*Spisula solidissima*), and
Blue Mussel (*Mytilus edulis*),
collected during Resource Assessment Cruise
8491, 8492, 8591, and 8592.

Surf Clam (*S. solidissima*)

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	37	0.07	0.87	4.80	<0.021	0.22	15.0
8591/ 6-22May85	37	0.033	0.13	0.71	0.025	<0.20	6.77
	47	0.056	0.27	1.5	0.083	0.24	13.0
	86	0.049	0.21	1.38	0.016	<0.20	11.2
8592/ 3-19Sep85	39	<0.020 -/3	0.45 0.28/3	0.9 0.7/3	<0.008 -/3	<0.20 -/3	6.10 0.92/3

Blue Mussel (*M. edulis*)

Cruise/ Date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	12	0.33	0.73	6.42		2.71	27.8
	73	0.180	0.16	5.54	<0.008	0.65	13.3
8492/ 10-27Sep84	34	0.22	0.20	1.61		0.31	22.2
8592/ 3-19Sep85	24	0.300	0.66	3.9	0.016	3.38	27.4

Table D-3

Mean Trace metal concentrations (μg/g wet wt.) for Ocean Quahog, *Arctica islandica*, collected during Resource Assessment Cruise 8491, 8492, 8591, and 8592.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	28	0.40	0.86	5.46		1.9	14.3
	50	0.280	0.25	2.54		1.5	9.73
8492/ 10-27Sep84	3	0.341	0.89	2.77	0.011	3.46	10.2
8591/ 6-22May85	6	0.214	0.82	2.5	0.133	1.7	12.1
	42		0.68	2.20		1.08	
	43	0.236	0.29	0.92	<0.008	0.53	7.75
8592/ 3-19Sep85	1	0.291	0.80	2.06	0.016	1.72	8.30

Table D-4

Mean trace metal concentrations (μg/g wet wt.)
for American Lobster, *Homarus americanus*,
collected in Salem Harbor

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
1June84	SESD	0.126	0.42	18.7	0.153	0.10	25.1
		0.117/5	0.23/5	3.7/5	0.047/5	0.07/5	3.3/5
19Nov85	S1	0.405	0.59	17.5	0.079	<0.11	18.0
		0.269/2	0.45/2	3.6/2	0.018/2	-/2	2.6/2
11Apr86	S2	0.218	0.43	25.5	0.084	<0.72	30.3
		0.042/3	0.16/3	2.2/3	0.012/3	-/3	3.9/3
	S3	0.342	0.16	24.6	0.153	<0.72	24.6
		0.152/3	0.06/3	1.7/3	0.025/3	-/3	4.8/3
15Dec86	S2	0.088	0.92	19.7	0.120	<0.72	23.3
		0.020/3	0.31/3	2.4/3	0.041/3	-/3	1.1/3
	S3	0.208	0.48	19.8	0.097	<0.72	21.7
		0.039/3	0.34/3	2.2/3	0.029/3	-/3	2.1/3

Table D-5

Mean trace metal concentrations (μg/g wet wt.)
for American Lobster, *Homarus americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
9Apr86	B2	0.121	0.18	32.8	0.187	<0.21	28.7
		0.105/5	0.07/5	7.9/5	0.022/5	-/5	4.9/5
19Dec86	B1	0.181	0.08	18.9	0.149	0.30	29.2
		0.095/3	0.06/3	0.9/3	0.017/3	0.21/3	0.4/3
	B2	0.138	0.10	22.5	0.136	0.28	25.7
		0.046/3	0.03/3	5.3/3	0.016/3	0.21/3	1.1/3
	B3	0.193	<0.06	29.4	0.172	0.48	28.2
		0.043/3	-/3	9.8/3	0.028/3	0.12/3	3.9/3

Table D-6

Mean trace metal concentrations (μg/g wet wt.)
for American Lobster, *Homarus americanus*, collected
during Resource Assessment Cruise
8491, 8492, 8591, and 8592.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	13	0.360	0.16	33.9	0.131	<0.21	41.3
	15	0.445	0.17	26.4	0.140	<0.21	40.9
		0.005/2	0.08/2	0.2/2	0.009/2	-/2	0.5/2
	19	0.690	0.16	28.9	0.167	<0.21	34.6
8492/ 10-27Sep84	1	0.159	0.38	19.6	0.155	0.28	20.8
	2	0.831	0.22	27.7	0.178	<0.68	38.0
	3	0.281	0.11	32.4		0.14	29.3
	5		0.18	32.5		0.24	
	18	0.461	0.06	19.4	0.289	<0.68	34.6
8591/ 6-22May85	4	0.102	0.15	22.0	0.052	<0.68	29.6
	5	0.378	0.08	19.1	0.207	<0.11	27.7
	9	0.490	0.07	41.6	0.109	<0.68	27.9
	22	0.257	0.17	36.7		0.19	38.3
	27	0.176	0.14	45.3		<0.68	32.7
8592/ 3-19Sep85	3	0.177	0.09	22.5	0.109	0.19	21.8
		0.056/2	0.00/2	4.4/2		0.19/2	0.8/2
	5	0.205	0.07	34.2		<0.11	17.8
		0.042/2	0.00/2	3.6/2		-/2	1.8/2
	6	0.390	0.05	32.2	0.112	<0.11	25.0
		0.083/2	0.01/2	1.0/2	0.000/2	-/2	3.9/2
	8	0.280	0.09	49.1		<0.11	22.1
		0.056/2	0.01/2	7.7/2		-/2	2.9/2
	13	0.645	0.08	20.9	0.081	0.14	22.8

Table D-7

Mean trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected in Salem Harbor.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
19Nov85	S1	<0.011	<0.01	0.13	0.027	<0.11	7.00
11Apr86	S1	0.012	0.07	0.25	0.062	<0.17	4.38
		0.010/5	0.03/5	0.07/5	0.024/3	-/5	0.63/5
	S2	<0.011	0.15	0.20	0.055	<0.21	4.78
		-/6	0.11/6	0.03/6	0.025/3	-/6	1.09/6
	S3	<0.011	0.08	0.27	0.043	<0.21	4.87
		-/6	0.02/6	0.04/6	0.012/3	-/6	0.44/6
15Dec86	S2	<0.011	0.05	0.26	0.032	<0.17	4.28
		-/3	0.00/3	0.03/4		-/3	0.83/3
	S3	0.017	0.06	0.21	0.024	0.19	4.01
		0.003/2	0.01/2	0.03/2	0.000/2	0.19/2	0.32/2

Table D-8

Mean trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected in Boston Harbor.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
21Nov85	B3	0.019	0.08	0.23	0.087	0.00	5.59
		0.012/5	0.02/5	0.04/5	0.041/5	0.00/5	0.52/5
9Apr86	B1	0.009	0.06	0.26	0.128	<0.21	7.56
		0.009/6	0.02/6	0.04/6	0.028/3	-/6	1.77/6
	B2	0.019	0.02	0.25	0.115	0.02	7.59
		0.006/6	0.02/6	0.06/6	0.054/3	0.04/6	1.23/6
	B3	0.012	0.05	0.32	0.104	0.08	7.74
		0.009/6	0.03/6	0.12/6	0.024/3	0.15/6	1.05/6
19Dec86	B1	0.001	0.05	0.51	0.107	<0.30	5.94
		0.006/4	0.00/4	0.57/4	0.011/3	-/4	1.15/4
	B2	<0.029	<0.08	0.25	0.157	<0.72	5.69
		-/4	-/4	0.08/4	0.031/3	-/4	0.66/4
	B3	<0.011	0.07	0.21	0.026	<0.30	4.55
		-/4	0.02/4	0.06/4	0.005/3	-/4	0.30/4

Table D-9

Mean trace metal concentrations (μg/g wet wt.)
for Winter Flounder, *Pseudopleuronectes americanus*,
collected during Resource Assessment Cruise
8491, 8492, 8591, and 8592.

Cruise/ date	Station #	Cd	Cr	Cu	Hg	Pb	Zn
8491/ 7-22May84	4	0.007	0.09	0.25		0.30	7.69
		0.009/2	0.07/2	0.11/2		0.30/2	2.54/2
	19	0.005	0.04	0.20	0.056	0.06	10.8
		0.005/2	0.02/2	0.03/2		0.04/2	1.0/2
	58	0.009	0.06	0.31	0.024	0.21	7.36
		0.000/2	0.01/2	0.02/2	0.003/2	0.04/2	0.63/2
8492/ 10-27Sep84	21	0.017	0.07	0.30	0.035	<0.54	7.70
		0.001/2	0.02/2	0.02/2		-/2	0.32/2
	35	<0.018	0.03	0.24		<0.54	6.93
	37	0.044	0.04	0.28	0.030	<0.54	6.48
		0.044/2	0.00/2	0.08/2	0.003/2	-/2	0.49/2
8591/ 6-22May85	60	0.039	0.12	0.51	0.086	<0.34	8.80
			0.00/2	0.06/2	0.010/2	-/2	
	63	0.019	0.16	0.43	0.065	0.17	7.29
		0.000/2	0.01/2	0.00/2	0.000/2	0.17/2	0.00/2
	81	0.027	0.14	0.45	0.065	0.28	7.41
		0.012/2	0.10/2	0.03/2	0.000/2	0.28/2	1.12/2
8592/ 3-19Sep85	8	<0.011	0.06	0.20	0.033	0.14	5.39
		-/2	0.03/2	0.07/2		0.01/2	0.24/2
	43	<0.011	0.02	0.20	0.018	<0.11	4.82
		-/2	0.02/2	0.01/2		-/2	0.26/2
	52	<0.011	0.03	0.30	0.018	<0.11	4.61
		-/2	0.03/2	0.07/2	0.000/2	-/2	0.11/2

APPENDIX E

Location coordinates for all coastal and harbor stations.

Table E-1

Station locations for coastal trace metal samples collected on resource assessment cruises 8491, 8492, 8591, & 8592.

Cruise no. 8491 (Spring 1984)

Sta. #	Date D/M/Y	Time (EST)	Loran C		Latitude/Longitude		Course (°T)	Tow Distance (naut.mil.)
4	7/5/84	1026	13960.5	44138.7	42° 03′	70° 34′	180	0.90
12	8/5/84	1244	13956.9	44302.9	42° 26′	70° 51′	323	0.82
13	8/5/84	1523	13894.1	44297.9	42° 27′	70° 43′	325	0.81
15	9/5/84	0820	13747.4	44358.0	42° 42′	70° 32′	155	0.84
19	9/5/84	1320	13814.9	44386.0	42° 43′	70° 44′	327	0.80
28	11/5/84	0828	13949.5	44156.7	42° 05′	70° 35′	135	0.90
37	12/5/84	1424	13786.1	44113.4	42° 06′	70° 08′	299	0.82
50	14/5/84	1534	13947.5	44048.3	41° 50′	70° 23′	143	0.86
58	16/5/84	0631	14094.3	43934.8	41° 30′	70° 33′	272	0.80
73	18/5/84	1038	13911.5	43916.0	41° 34′	70° 04′	195	0.88

Cruise no. 8492 (Fall 1984)

Sta. #	Date D/M/Y	Time (EST)	Loran C		Latitude/Longitude		Course (°T)	Tow Distance (naut.mil.)
1	10/9/84	0656	13971.9	44068.3	41° 52′	70° 28′	352	0.83
2	10/9/84	0816	13966.3	44105.0	41° 58′	70° 31′	146	0.73
3	10/9/84	0940	13987.4	44110.1	41° 58′	70° 35′	032	0.80
5	11/9/84	1139	13976.1	44317.4	42° 27′	70° 55′	169	0.84
18	13/9/84	0752	13858.1	44300.9	42° 29′	70° 38′	031	0.74
21	14/9/84	0832	13935.0	44141.1	42° 04′	70° 31′	291	0.80
34	16/9/84	1015	14216.5	43895.3	41° 21′	70° 47′	076	0.80
35	16/9/84	1108	14217.6	43895.0	41° 21′	70° 47′	102	0.86
37	16/9/84	1353	14284.3	43928.5	41° 23′	71° 00′	177	0.86
86	26/9/84	1400	13922.0	43935.8	41° 36′	70° 07′	148	0.91

Cruise no. 8591 (Spring 1985)

Sta. #	Date D/M/Y	Time (EST)	Loran C		Latitude/Longitude		Course (°T)	Tow Distance (naut.mil.)
4	7/5/85	0600	13958.4	44053.1	41° 51′	70° 25′	228	0.81
5	7/5/85	0726	13953.1	44088.2	41° 56′	70° 28′	165	0.87
6	7/5/85	0852	13983.2	44111.9	41° 58′	70° 34′	157	0.86
9	7/5/85	1246	13935.6	44163.2	42° 06′	70° 33′	208	0.84

(continued)

Table E-1 (continued)

Cruise no. 8591 (Spring 1985) continued

Sta. #	Date D/M/Y	Time (EST)	Loran C		Latitude/Longitude		Course (°T)	Tow Distance (naut.mil.)
22	10/5/85	0747	13914.4	44335.1	42° 32′	70° 50′	142	0.78
27	10/5/85	1403	14001.4	44255.3	42° 17′	70° 52′	145	0.75
37	12/5/85	1106	13872.1	44035.7	41° 51′	70° 11′	041	0.81
42	13/5/85	1006	13811.3	44126.3	42° 06′	70° 13′	241	0.78
43	13/5/85	1151	13750.0	44091.1	42° 04′	70° 00′	306	0.87
47	14/5/85	0855	13770.0	44058.9	41° 58′	69° 59′	334	0.68
60	16/5/85	1316	14156.5	43982.4	41° 34′	70° 46′	214	0.83
63	17/5/85	0637	14072.9	43919.7	41° 29′	70° 28′	288	0.81
81	20/5/85	1101	14063.9	43810.8	41° 14′	70° 17′	047	0.68
86	21/5/85	0735	14202.2	43905.1	41° 23′	70° 46′	040	0.87

Cruise no. 8592 (Fall 1985)

Sta. #	Date D/M/Y	Time (EST)	Loran C		Latitude/Longitude		Course (°T)	Tow Distance (naut.mil.)
1	3/9/85	1353	13954.0	44046.3	41° 50′	70° 23′	242	0.88
3	4/9/85	0621	13988.0	44045.2	41° 49′	70° 28′	182	0.47
5	4/9/85	1114	13982.6	44146.4	42° 03′	70° 38′	146	0.87
6	4/9/85	1232	13936.4	44161.7	42° 07′	70° 33′	193	0.83
8	5/9/85	0647	13974.8	44256.6	42° 18′	70° 48′	088	0.52
13	6/9/85	0649	13760.8	44339.1	42° 39′	70° 31′	160	0.52
24	7/9/85	0803	13856.0	44312.9	42° 31′	70° 40′	027	0.78
39	9/9/85	1303	13844.3	44036.0	41° 52′	70° 07′	020	0.85
43	10/9/85	1149	13879.4	44030.9	41° 50′	70° 11′	036	0.85
52	12/9/85	0923	14251.7	43882.4	41° 18′	70° 51′	296	0.83

Table E-2

Station locations for trace metal samples collected in Boston and Salem Harbors.

Boston Harbor

Station	Latitude/Longitude		Station	Latitude/longitude	
BH5C.1	42° 18′	71° 0′	B3	42° 21′	70° 58′
BH1	42° 22′	70° 59′	B2	42° 18′	70° 57′
BH7	42° 16′	70° 58′	B1	42° 17′	70° 58′

Salem Harbor

Station	Latitude/Longitude		Station	Latitude/longitude	
TP	42° 32′	70° 52′	S3	42° 31′	70° 58′
WI	42° 31′	70° 52′	S2	42° 32′	70° 50′
FR	42° 30′	70° 53′	S1	42° 31′	70° 49′
			SESD	40° 32′	70° 50′